Melville
Shipping Ltd.

TP 8232 E

EVALUATION AND DEFINITION OF THE EXTENT OF SUPERSTRUCTURE ICING AS IT MAY RELATE TO SHIPS SAFETY AND OPERATIONS FOR THE EAST COAST OF CANADA

For

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17. Abstract

The focus of this report is the problem of ice accretion on vessels which will be required for year-round oil and gas exploration and production operations off the Canadian east coast, particularly in the Hibernia region.

Icing of ships in the area under study is a recurring problem and is experienced between December and March. There is a lack of reliable quantitative data on icing and such as exists is mainly reported by untrained observers on board fishing vessels.

The limited data available has been used to calculate the effect of ice accretion on offshore logistics/supply ships, which are most likely to be affected. Based upon the applicable icing allowances in the Large Fishing Vessel Regulations, it appears that these vessels would be unlikely to experience a reduction in stability. Nevertheless, icing will give rise to operational problems with exposed equipment, lifesaving and firefighting appliances and may endanger ships' crews.

Investigations into methods of anti-icing and de-icing have revealed that although a great deal of laboratory work has been carried out, little field testing has been done of promising methods.

The report recommends a scientific testing programme which will expand existing knowledge and provide possible solutions to the icing problem on offshore vessels.

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17. Résumé

Le présent rapport s'intéresse aux problèmes de givrage sur les bateaux utilisés pour la prospection et la production pétrolières et gazières au large de la côte Est du Canada, particulièrement dans la région du champ pétrolier Hibernia.

L'accumulation de glace sur les bateaux constitue, dans la région étudiée, un problème récurrent qui se manifeste de décembre à mars. Il y a peu de données quantitatives fiables sur ce phénomène et celles qui existent ont généralement été rapportées par des observateurs non spécialisés, à bord de bateaux de pêche.

Le peu de données disponibles a été utilisé pour calculer les effets de l'accumulation de glace sur les bateaux de servitude-ravitaillement, lesquels sont les plus susceptibles d'être touchés par le phénomène. Il semble peu probable que leur stabilité soit compromise, étant donné les accumulations de glace prises en compte dans la réglementation sur les gros bateaux de pêche. Toutefois, les accumulations de glace peuvent rendre inopérants les apparaux ainsi que le matériel de sauvetage et de lutte contre l'incendie exposés aux intempéries et peuvent, de ce fait, mettre les équipages en danger.

La recherche documentaire sur les méthodes de lutte contre le givrage a révélé que, si bon nombre de travaux dans ce domaine ont été réalisés en laboratoire, peu de méthodes prometteuses ont été éprouvées in situ.

Le rapport recommande de mettre sur pied un programme scientifique d'essai permettant d'approfondir les connaissances dans ce domaine et de proposer des solutions aux problèmes d'accumulation de glace sur les bateaux hauturiers.

18. Mots-clés	19. Diffusion
Bateau, bâtiment, accumulation de glace, givrage, Hibernia, côte Est, Atlantique, antigivrage, dégivrage, sécurité.	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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SUMMARY

Ice accretion on ships which operate in hostile waters and experience extreme cold has been a serious problem for many years, primarily because of its adverse effect on ship stability. Most affected are smaller vessels with low freeboard as is characteristic of fishing vessels. There is concern that ice accretion may seriously affect the safety and operations of vessels which are planned for year round operations associated with development and production of oil and gas off the East Coast of Canada, particularly in the region of Hibernia. This report addresses that concern.

The report substantiates that the primary cause of ice accretion on ships is sea spray in conjunction with sub-freezing air temperatures, sea temperatures of $6^{o}C$ and below, and wind speeds in excess of 10 knots. A secondary cause arises from atmospheric sources and may be due to freezing fog, freezing rain or snow. These climatic conditions prevail during the months of December to March off the east coast of Canada and may be encountered anywhere within an area extending from about 40^{o} latitude to 60^{o} latitude and for a distance offshore of about 200 miles. Within this region lies the Hibernia oil and gas exploration field.

Shipowners whose vessels operate in east coast waters have confirmed that, in addition to causing a reduction in ship stability, ice accretion has, on occasion, been so severe that all exposed operational and safety equipment has been completely encased in ice and could not have been used in an emergency.

Many model studies have been carried out in attempts to predict rates and severity of icing under different climatic conditions, but the studies have not been substantiated to any degree owing to the lack of adequate field data from trained observers. Available Canadian field data is in the form of east coast icing reports from ships, held by the Canadian Coast Guard Ship Safety Branch. This data has been used to calculate the effect of icing on the stability of offshore logistics/supply vessels which, due to their low freeboard, are the type most likely to be affected by ice accretion. The calculations indicate that the icing allowance for these vessels, within the appropriate regulations made under the Canada Shipping Act, is sufficient to ensure vessel stability. However, it is clear that for the offshore production vessels proposed, safety may be compromised as the result of icing up of deck machinery and lifesaving and firefighting equipment.

Anti-icing and de-icing methods have been researched and documented. The research reveals that although a number of laboratory experiments have been carried out, few field applications have been attempted of methods which show promise.

In pursuit of solutions to the icing problems, recommendations are made for controlled laboratory and shipboard experiments which will test, then evaluate the most promising and cost-effective methods of anti-icing and de-icing.

SOMMAIRE

L'accumulation de glace sur les bateaux naviguant en eaux hostiles par températures très froides constitue un grave problème depuis de nombreuses années, essentiellement parce qu'elle affecte la stabilité du bateau. Les plus touchés par le phénomène sont les petits bateaux à faible franc-bord, typiquement les bateaux de pêche. On craint que l'accumulation de glace ne compromette sérieusement la sécurité et les opérations des bateaux utilisés pour la prospection et la production pétrolières et gazières au large de la côte Est du Canada, notamment dans la région du champ pétrolier Hibernia. C'est de ce problème que traite le présent rapport.

Le rapport confirme que l'accumulation de glace sur les bateaux est essentiellement attribuable aux embruns, conjugués à des températures de l'air sous le point de congélation, des températures de l'eau de mer inférieures à 6°C et des vitesses du vent supérieures à 10 noeuds. Elle peut également avoir une origine purement atmosphérique: brouillard givrant, pluie verglaçante ou neige, phénomènes météorologiques que l'on retrouve de décembre à mars au large de la côte Est du Canada, n'importe où entre 40° et 60° de latitude et jusqu'à environ 200 milles des côtes. C'est dans cette région que se trouve le champ de prospection pétrolière et gazière Hibernia.

Les armateurs dont les bateaux évoluent au large de la côte Est ont confirmé qu'en plus de réduire la stabilité du bateau, l'accumulation de glace est parfois telle que les apparaux et le matériel de sauvetage exposés aux intempéries se retrouvent pris dans la glace, ce qui les rendraient inutilisables en cas d'urgence.

Bon nombre d'études de simulation ont été entreprises dans le but de prévoir l'importance du givrage et sa vitesse de formation sous diverses conditions climatiques, mais aucune d'entre elles n'a pu être étayée en raison du manque de données concrètes appropriées fournies par des observateurs compétents. Les données canadiennes sont tirées des rapports d'accumulation de glace faits à la Division de la sécurité des navires de la Garde côtière canadienne par les bateaux de la côte Est. Ces données ont été utilisées pour calculer les effets du givrage sur la stabilité des bateaux de servitude-ravitaillement qui, en raison de leur faible franc-bord, sont les plus susceptibles d'être affectés par les accumulations de glace. Il en ressort que les accumulations de glace prises en compte dans les règlements de la Loi sur la marine marchande du Canada sont suffisantes pour assurer la stabilité du bateau. Il est toutefois clair que la sécurité des bateaux en question risque d'être compromise en raison des accumulations de glace sur les apparaux de pont ainsi que sur le matériel de sauvetage et de lutte contre l'incendie exposé aux intempéries.

Une recherche documentaire sur les méthodes de lutte contre le givrage a révélé que, même si un certain nombre d'expériences en laboratoire ont été effectuées, elles ont donné lieu à peu d'applications in situ des méthodes prometteuses.

En vue d'apporter des solutions aux problèmes d'accumulation de glace, le rapport recommande de procéder à des expériences contrôlées, en laboratoire et en mer, visant à éprouver les méthodes les plus prometteuses et les plus rentables en matière de dégivrage et d'antigivrage.

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1. INTRODUCTION

Ice accretion on ships and marine structures has frequently led to the loss of ships and is a problem experienced in certain waters of the world at particular times of the year. One area where severe icing is experienced is off the eastern seaboard of Canada during the winter months. Within this area is the region where oil and gas exploration is taking place, and consequently there has been a large influx of drilling rigs and their support vessels. As oil and gas fields are delineated and come into production, more vessels will be required to operate in the area throughout the year.

Icing of ships and structures causes slippery surfaces and creates hazards to personnel; renders inoperable exposed and often vital machinery and equipment and in the extreme case may cause a ship or structure to capsize due to the increase of topside weight. The vessels which are principally at risk of capsizing are small ships and fishing vessels.

Much of the information of the incidence of icing comes from reports from fishing vessels as these vessels regularly operate in regions where icing is common. The majority of statistics compiled on icing are from observations by untrained observers rather than from scientific measurements. Since reliable field data is scarce, the reports and studies of icing often provide data with a large degree of variation.

This report discusses the causes of icing with particular reference to the Hibernia region of the eastern seaboard of Canada and the affects of icing on the types of vessel which may operate in this region.

2. CAUSES OF ICE ACCRETION

2.1 General

Icing of ships is caused by the presence of water or moisture in sub-freezing temperatures. The principal sources of icing are sea spray and water shipped on deck, and rain, snow, or freezing fog.

2.2 Sea Spray Icing

Sea spray is the most prominent and dangerous source of icing. Sea spray is generated by a ship as it makes headway through the water and is intensified by wind driven spray or mist from wave crests. Wave height and frequency have a bearing on the amount of spray which will break over a vessel. Wind force, water depth and fetch affect wave height. The reduction of water depths to 100-150 m at the edge of the continental shelf will affect the large deep sea waves approaching from the ocean and create steeper waves of shorter period, leading to greater spray potential (Jorgensen 1982). Table 1 shows expected wave heights depending on wind force and fetch.

TABLE 1

Expected Wave Heights Depending On Wind Force And Fetch

Beaufort Force of Wind	Theoretical Maximum wave height, unlimited duration and fetch	Duration of winds, (hours), with unlimited fetch, to produce percent of maximum wave height indicated			Fetch (nautical miles), with unlimited duration of blow, to produce percent of maximum wave height indicated		
		50%	75%	90%	50%	75%	90%
3	0.6 m (2 ft.)	1.5	5	8	3	13	25
5	2.4 m (8 ft.)	3.5	8	12	10	30	60
7	6.1 m (20 ft.)	5.5	12	21	22	75	150
9	12.2 m (40 ft.)	7	16	25	55	150	280
11	21.3 m (70 ft.)	9	19	32	85	200	450

The height to which sea spray may be expected to reach, is important in determining the extent to which ice may form on a ship. The height reached by sea spray is dictated by wave height and wind speed, as the stronger the wind, the higher the spray will rise. Sea spray seldom carries higher than 20 m above the sea surface although there have been reports of icing caused by wind whipped sea spray at heights of 60 m above sea level (Brown & Roebber, 1985). However, very little research has been carried out to determine the vertical distribution of icing on ships from sea spray.

Air temperature, water temperature and wind speed must occur within a certain range for sea spray to form ice on a structure, although some differences of opinion exist regarding limiting conditions.

Minsk (1984) states that most observers agree that icing from ship generated sea spray can occur with sea surface temperatures of up to 6°C with sub-freezing air temperatures and wind speeds exceeding about 10 knots, and that significant spray icing has occurred where sea temperatures are in the order of 5°C. However, Jorgensen (1982) has presented data indicating considerable icing from spray associated with sea temperatures as high as 8°C.

With respect to the lower limit of air temperature, views have been expressed that at -18°C water droplets from spray freeze during their flight through the air, and strike the surface as dry crystals which do not adhere and therefore do not produce icing (Stallabrass; Tabata; Jorgensen; Vasil'Yeva; Bardarson). This has been disputed from observations of serious sea spray icing at air temperatures from -26°C to -29°C (Shekhtman 1971; Panov 1976).

The water particles or droplets forming the sea spray are initially at the same temperature as the sea. During subsequent flight the droplets are supercooled by giving up heat to the surrounding atmosphere. The rate of cooling and the temperature on impact are determined by droplet size, sea and air temperatures, and the length of time in the air.

The equilibrium freezing temperature of fresh water at atmospheric pressure is 0°C. The effect of dissolved solids in sea water, is to lower the freezing temperature. Spray droplets can cool to below their equilibrium freezing temperature, and do not freeze, but exist in a liquid state known as supercooled. When supercooled droplets impact with a cold surface, the surface acts as a nucleating agent to initiate freezing.

Some, if not all of the impinging water freezes in the immediate area of impingement. Significant icing will also occur with droplets which have not attained a supercooled state prior to impact, providing the air temperature is sufficiently low to produce rapid freezing following impact on a structure.

Ono (1968) states that since a spray of sea water contains salt, it does not wholly freeze. A proportion freezes, rejecting its salt, which results in an increase in salt concentration in the unfrozen liquid fraction (brine), the freezing temperature of which steadily falls.

Lock (1972) supports Ono, asserting that salinity becomes important if sea spray droplets freeze subsequent to impact. When only a part of a drop is frozen, the rejected salt remains in the unfrozen liquid, thereby depressing the freezing point of the latter still further. It has been found that the salinity difference between the solid and liquid solutions depends on the rate of freezing. In general, the lower the rate of freezing the greater the opportunity for the solid phase to reject the salt, and hence the purer will be the ice formed. The purer the ice the harder it is, and the more difficult to remove.

Stallabrass (1975) contends that the nature and properties of ice formation resulting from the impingement of salt water droplets have not been studied in any detail, however, it would be expected initially that the ice would be soft and porous as a result of numerous brine pockets

between the ice crystals, but as the brine drains out the ice would become harder and adhere more strongly.

Sea spray icing also has been reported by the fishing fleets of Russia, Germany, Japan, United Kingdom, Norway and Iceland. Reports from Canadian sources are largely in accordance with those of other countries. Sea spray icing in Canadian east coast waters is most common in ranges of air temperature of -2°C to -20°C in conjunction with wind speeds greater than 13 knots, while moderate to severe icing has been experienced with winds in excess of 25 knots.

2.3 Atmospheric Icing

Atmospheric icing is caused by freezing rain, freezing fog or snow. Freezing rain and fog form typically a uniform layer of hard ice well bonded on all surfaces, which is reported to have greater adhesion than ice formed from salt water. On the other hand, wet snow although it will freeze on surfaces at sub-zero temperatures, forms ice of a porous nature with low mechanical strength.

Freezing fog is formed over the sea when the temperature difference between surface water and air is at least 9°C and the air temperature is below zero (Jorgensen). The fog is comprised of supercooled water droplets which, when they strike a sub-freezing surface, form a rime or glaze ice. The ice formed may be hard or soft depending on the rate of heat loss from the water droplets. The characteristics of the types of ice formed are described in Table 2.

Table 2

Types Of Ice From Atmospheric Sources

Type Of Ice	Appearance	Density (g/cm^3)	Conditions Of Formation
Glaze	A hard, well-bonded, generally clear homogeneous ice	0.7 -0.9	Supercooled water droplets at a temperature close to freezing (0° to 3°C) and wind speeds of 1-20m/s
Hard rime	A hard, granular white or translucent ice growing in the direction of the wind	0.1 -0.6	Supercooled water droplets at a temperature of -3° to -8°C, wind speeds generally 5-10 m/s.
Soft rime	A white, opaque, granular ice with delicate structure only loosely bonded, growing in the direction of the wind.	0.01-0.08	Supercooled water droplets at a temperature of -5° to -25°C and low wind speed (1-5 m/s)

Freezing rain is formed when snow melts as it passes through a warm layer of air and is then supercooled as it passes through an underlying cold layer. Freezing rain generally causes ice accretion when temperatures range from -3°C to -0°C with wind speeds of up to 30 knots (Horjen 1983).

There are wide differences of opinion regarding the hazard posed by atmospheric icing from freezing rain and fog. Jorgensen (1982) describes how a trawler was nearly lost by capsizing east of Greenland after entering a vast area of supercooled fog, and quotes another trawler incident off Bear Island when in similar circumstances, 10 cm of ice accummulated over a 12 hour period on deck and 30 cm on hull sides. Other authors also regard atmospheric icing as a serious danger (Shekhtman 1968; Vasil'Yeva 1971) while some consider its importance exaggerated (Bardarson 1973; Tabata et al 1963; Borisenkov and Panov 1972).

Very little is known about the effect of icing due to snow, particularly with respect to its simultaneous occurrence with sea spray icing. Although a theory of mixed snow/spray icing has been presented by Horjen and Vefsnmo (1984), it is with the caveat that given the potential importance of combined snow and spray accumulation, there is a need for greater understanding of the mixed accretion process. Makkonen (1984) also reports that a satisfactory theory for the rate of wet snow accumulation still needs to be developed, adding that estimating the intensity and probability of atmospheric icing on sea structures is difficult because a large number of environmental factors are involved, and representative data are lacking.

2.4 Ship Related Factors

The amount of sea spray generated and its dispersion on board ship, is dependent on more than climatic conditions. Other factors which affect spray and consequent ice accretion are:

- form and size of the vessel
- speed and direction of the ship relative to the wind
- superstructure configuration
- arrangement of deck equipment

The design of the bow is of special importance since the greater the flare the more the generated spray is thrown outwards away from the ship. The size of the ship also has a great influence on ice accretion. Generally, the larger the ship, the greater is its freeboard, with decks, masts, rigging and superstructure at a higher level above the sea. Depending on the height of spray, the amount and thickness of ice accreted on larger ships will be much less than that experienced by smaller ships. The height and design of superstructure and the extent and arrangement of deck equipment will determine the amount of spray which will impact, and hence the degree of ice accretion.

The speed and direction of the ship relative to the wind and waves significantly affects the amount of spray generated. Regardless of the

size of the ship, and whatever the sea state, the greater its speed, the more frequently the vessel will impact the waves thus increasing the potential for spray generation.

With respect to direction of waves striking the ship, the amount of spray generated will increase when the waves are off the bow as there will be greater exposure of the hull to the waves. Furthermore, this will allow more spray to strike the ship further aft where, especially on small vessels like offshore supply boats or similar vessels, the freeboard is less. Russian data indicates that spray generation is greatest when the wind relative to the ship is in a direction of up to 45° to the bow (Panov 1976).

A Japanese investigation of icing on patrol vessel supports the Russian data. Figure 1 shows the ice accretion measured at two different relative wind directions. Although the wind speed was moderate, the variation in icing with course and speed is evident. In both cases (ie. wind and waves at 30° and 60° on the bow) ice accretion reduced significantly with a moderate reduction in speed from 12.5 to 10.7 knots, due to the less carrying capacity of the wind resulting from the slower relative speed.

Similarly, tests conducted by the British Ship Research Association showed that icing due to spray was far more severe with the wind 30° to 40° on the bow than when it was head on (Jorgensen 1982).

2.5 Ice Accretion Modelling

Laboratory modelling of ice accretion from given sea and atmospheric conditions has been attempted by a number of researchers as a method of:

a) determining by empirical means, estimates of icing potential and severity.

b) estimating the rate of icing.

Although much of the past modelling work has concentrated on atmospheric icing because of problems experienced by shore industry, increasing interest in recent years in marine icing has led to the development of sea spray/atmospheric models. Major difficulties, however, have been experienced in attempting to compare the accuracy of model predictions with actual icing events. The reason is that ship generated spray is unique to each vessel, and very little information is available so far on the characteristics of wave generated spray (ie. droplet size, liquid water content and variations with height, and with meteorological and oceanographic parameters) which is essential for realistic predictions of ice accretion.

Table 3 is representative of some of the ice accretion modelling work which has been carried out from the late 1960's (Brown & Roebber 1985).

FIGURE 1

DISTRIBUTION OF ICING ON JAPANESE PATROL VESSELS
DEPENDING ON COURSE AND SPEED

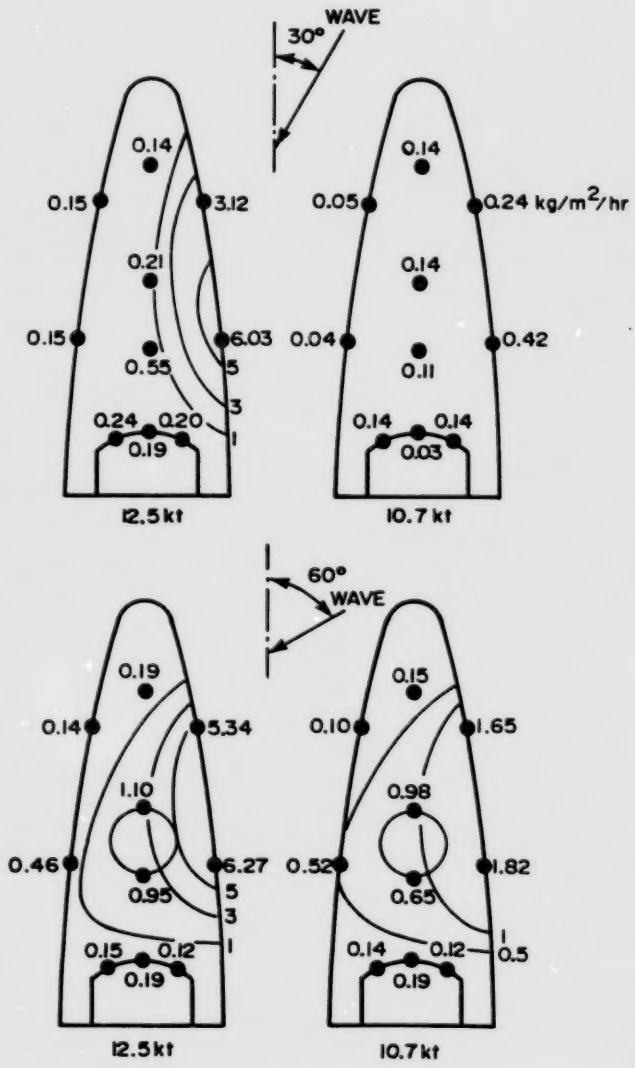

TABLE 3

ICE ACCRETION MODELLING

Comiskey et al (1984)	Same as Wise and Comiskey (1980) except tht nomogram severity classes re-organized based on vessel icing data from Alaskan waters.	Air Temperature Wind Speed Sea Temperature	Freezing Spray Icing (no information on growth regime or ice density)	Icing severity class in inches/3hours (5 classes)
Chaine and Skeates (1974)	Semi-empirical model for calculating radial ice accretion thickness on conductor from freezing precipitation. Uses climatological data.	Wind Speed Freezing Precipitation Rate Conductor Radius	Glaze	Horizontal, vertical and equivalent radial ice thickness from icing storm. Also computes ice and wind loadings during storm.
Kachurin et al (1974)	Heat balance expression for theoretical growth rate of freezing spray icing on cylinder. Theoretical results empirically related to observed ice accretion loads on Russian trawlers and simplified in nomogram form.	Wind Speed Air Temperature Sea-surface Temperature Wave Height Sea-surface Salinity	Freezing Spray Icing (no information on ice density or growth regime)	Ice accretion rate on vessel (tons/hr).
Horjen (1983)	Theoretical two dimensional model for sea spray or atmospheric icing on vertical cylinders or plates. Model incorporates expressions for vertical variation in wind and wave generate liquid water content with elevation above sea surface. Model does not consider time-dependent effects or run-off in the icing process. Model includes calculation of heat required for anti and de-icing. Model applied to oil rig by structural segmentation. All liquid water sources treated separately in model.	Wind Speed Visibility Precipitation Rate Wave Height Sea-surface Temperature Sea-surface Salinity Droplet Size Distribution Cylinder Diameter/ Characteristic Length	Freezing Spray Rime Freezing Rain (Ice density of 810 kg/m^3 assumed for spray icing. Variable ice density expression from Macklin (1962) used for atmospheric icing). Model applicable for wet or dry growth conditions.	Icing intensity, ice thickness and heat required for de-icing and anti-icing cylinders and plates as a function of elevation above sea surface. Model used to provide estimates of ice loadings on offshore platforms.

TABLE 3 (CONT'D)

ICE ACCRETION MODELLING

Horjen (1981)	Heat balance models of ice accretion from sea spray or atmospheric icing (separate expressions) on cylinders or flat plates. Analytical expressions are presented for computing atmospheric icing rates under wet growth regimes ($n<1.0$ or $T_s = 0^{\circ}C$). Solution for heat balance under freezing spray conditions not provided	Wind Speed Liquid Water Content (atmos.) Wave Height Air Temperature Sea-surface Temperature Surface Type (cylinder/plate) Characteristic Length of Surface	Freezing Spray Atmospheric Icing (no information given on ice density)	Icing rate (kg/m^2s)
Makkonen (1981)	Analytical expressions for determining ice accretion rate on stagnation line of cylinder	Air Temperature Wind Speed Liquid Water Content Droplet Diameter Cylinder Radius	Rime Glaze	Icing rate on stagnation line of cylinder
Horjen and Vefsnmo (1984)	Extension of Horjen (1983) model to include combined effects of all liquid water content sources, runoff terms in thermodynamics, revised expressions for wind and wave generated spray, and computation of icing rates on inclined surfaces. Model does not include time-dependent effects.	Same as Horjen (1983)	Mixed Accretion (freezing spray and snow or hail) Freezing Spray Snow or Hail (constant ice density assumed of 350 kg/m^3 for spray. Mixed accretion density varies with height above the surface) Model applicable to wet or dry growth regimes.	Same as Horjen (1983)
Itagaki (1984)	Semi-empirical model for ice accretion rate on stationary structures. Only considers wind-generated spray flux and uses data from ONO (1964) to derive empirical expression relating the freezing fraction to air temperature. Collection efficiency assumed equal to 1.0.	Wind Speed Air Temperature	Freezing Spray (no information on growth regime or ice density)	Icing rate of surface exposed to wind-generated spray ($kg/hr\ m^2$).

TABLE 3 (CONT'D)

ICE ACCRETION MODELLING

Sawada (1966)	Curves of icing severity related to wind speed and air temperature. Severity curves based on reports from Japanese patrol and fishing vessels.	Air Temperature Wind Speed	Freezing Spray Icing (no information on gorwth regime or ice density)	Qualitative indication of severity (i.e. no ice, light, moderate, severe)
Mertins (1968)	Nomograms for determining severity of sea spray icing conditions for fishing vessels. Nomograms derived from 400 fishing vessel icing reports from mainly North Atlantic area.	Air Temperature Wind Speed (Beaufort Force) Sea Temperature	Freezing Spray Icing (no information on growth regime or ice density)	Icing severity class in cm/24 hours (4 classes)
Stallabrass (1980)	Heat balance expression for the theoretical icing rate of a cylinder exposed to freezing spray icing conditions. Model 'tuned' using trawler icing data from the East Coast of Canada.	Air Temperature Sea-surface Temperature Droplet Diameter Wave Height Wind Speed	Freezing Spray Icing (wet or dry growth) Ice density of 900 kg/m^3 assumed.	Icing rate (kg/m^2s) or growth rate of ice thickness (mm/h) on fishing trawlers.
Wise and Comiskey (1980)	Nomogram for determining icing severity of ships in Northeast Pacific area. Nomogram derived by integrating Mertins (1968) nomogram and adjusting air temperatures to take into account lower relative humidities in Northeast Pacific area.	Air Temperature Wind Speed Sea Temperature	Freezing Spray Icing (no information on growth regime or ice density)	Icing severity class in inches/24 hours (5 classes)

3. GEOGRAPHY AND SEASONALITY OF ICING - CANADIAN EAST COAST

An analysis of environmental parameters carried out by Mortsch et al in their Canadian East Coast Climatological Atlas (1985) indicated that all the elements to cause potential icing were present at certain times of the year off the east coast. They prepared a set of contour maps which present the percentage frequency of moderate or greater (ie. 1.25 mm/hr. or more) freezing spray potential. During preparation of the maps, account was taken of wind speed, wave height and period, air and sea temperatures and freezing precipitation throughout the year.

The statistics which form the basis of the contour maps, indicate that ice accretion potential exists off the east coast from December to March. As an example, the December map is reproduced as Figure 2 with January to March included as Appendix 1.

Stallabrass (1980) reported the locations of icing encounters given by reports from some 450 Canadian ships. These locations are shown on Figure 3. Comparing the Stallabrass figure with the contoured maps, the icing actually observed compares well with that predicted by Mortsch et al. However, by the end of the 1983-84 icing season approximately 1,000 reports of icing had been received through the Canadian Coast Guard icing report system, and Figure 4 shows the monthly distribution of icing based on these reports.

The reports indicate that the main icing season for eastern Canadian waters is January to March, although in the Labrador - Davis Strait area it can extend from October to March and in the Gulf of St. Lawrence, from November to March. During the icing season, most open water areas for a distance of about 200 nautical miles off the east coast experience similar climatic conditions.

The northern limit of significant icing in east coast waters is the edge of the ice pack since wave action and hence spray is inhibited by ice cover. A clearly defined southern limit for offshore icing is at about $40^{o}N$ latitude. This is as a result of the flow of the Gulf Stream which creates a large sea surface temperature gradient off the Grand Banks of Newfoundland and the Scotian Shelf. As the Hibernia area lies at latitude $46/47^{o}N$ and is about 170 nautical miles east of Newfoundland, it is well within the boundaries of icing occurrence.

FIGURE 2
ICE ACCRETION - DECEMBER

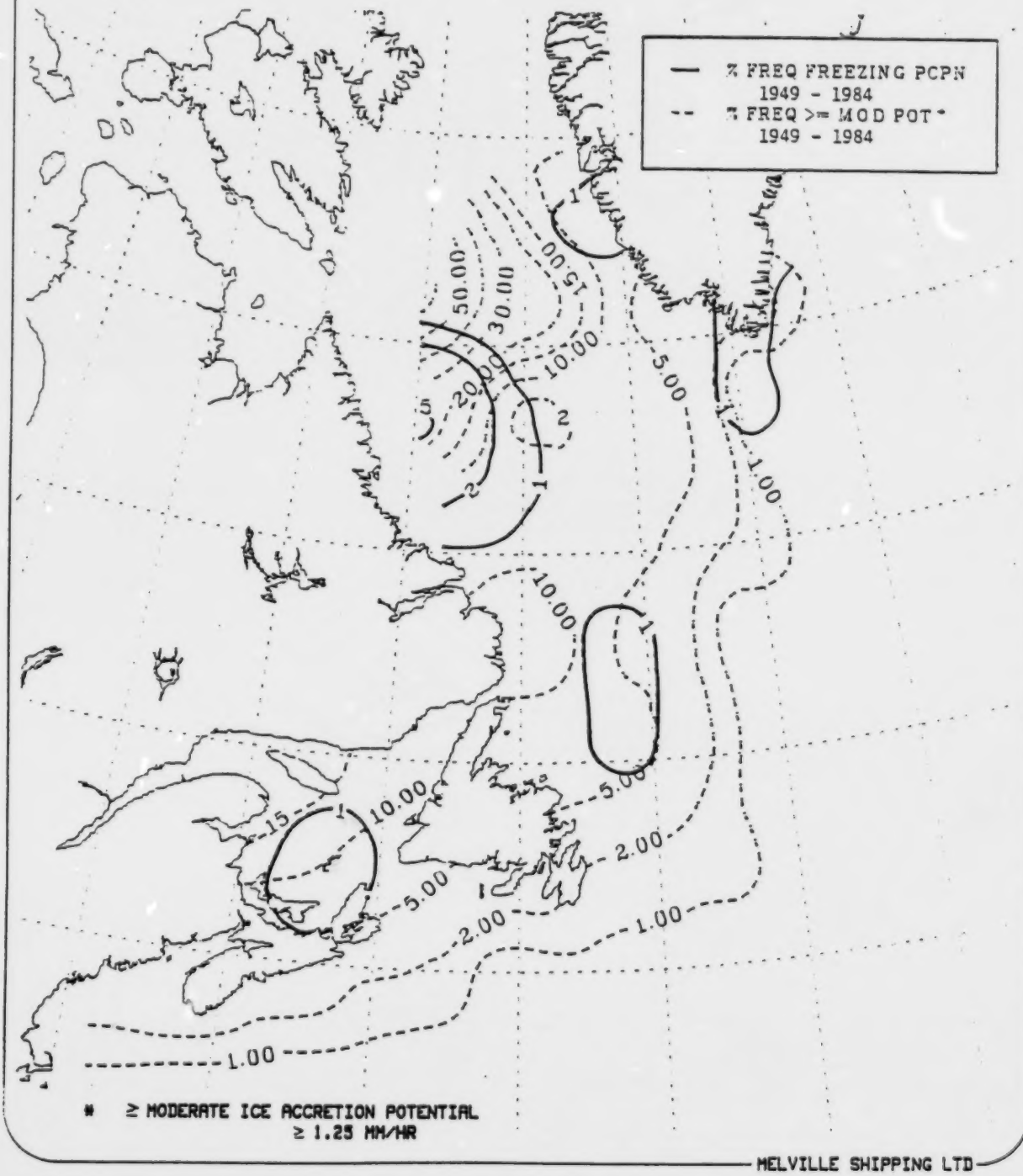

FIGURE 3
LOCATIONS OF REPORTED SHIP ICING
OFF EASTERN CANADA

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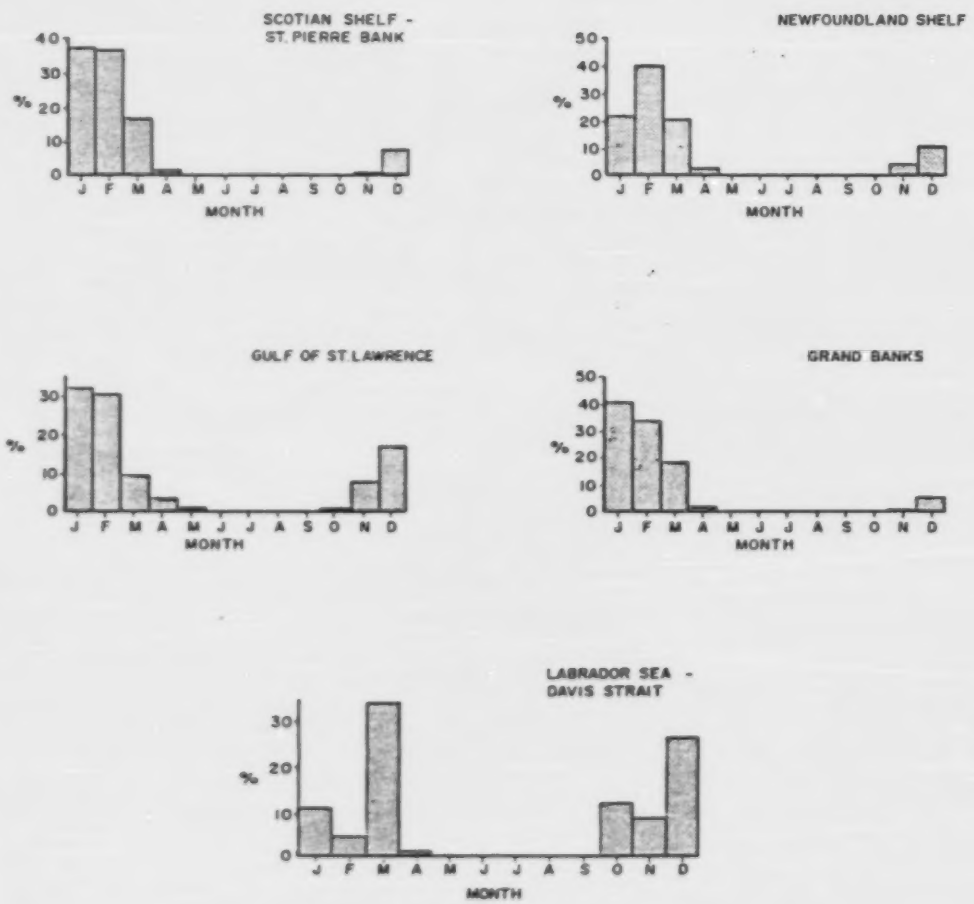
FIGURE 4
MONTHLY DISTRIBUTION OF SHIP ICING REPORTS FOR MARINE AREAS OFF EASTERN CANADA


SCOTIAN SHELF - ST. PIERRE BANK
NEWFOUNDLAND SHELF
GULF OF ST. LAWRENCE
GRAND BANKS
LABRADOR SEA - DAVIS STRAIT
%
MONTH
J F M A M J J A S O N D

4. MARINE ICING EXPERIENCE

4.1 General

Ship icing data has been collected from the late 1960's onwards by a number of countries, including the United States, Japan, Sweden, West Germany and the Soviet Union. The collection of field data has primarily been by means of questionnaires distributed to masters of fishing vessels in particular, since historically they have been the vessels most affected by ice accretion.

Administered by Coast Guard Ship Safety, Canada has its own icing report programme, also mainly from fishing vessels, which form its data base source.

4.2 Ship Icing Severity

The severity of icing is expressed commonly by the rate of ice accretion and is categorised in the literature as follows (Bandarson, Jorgensen, Mortsch et al):

1.	No Icing	
2.	Low	1 to 3 cm/24 hours
3.	Moderate	4 to 6 cm/24 hours
4.	Heavy	7 to 14 cm/24 hours
5.	Very Heavy	15 to 24 cm/24 hours

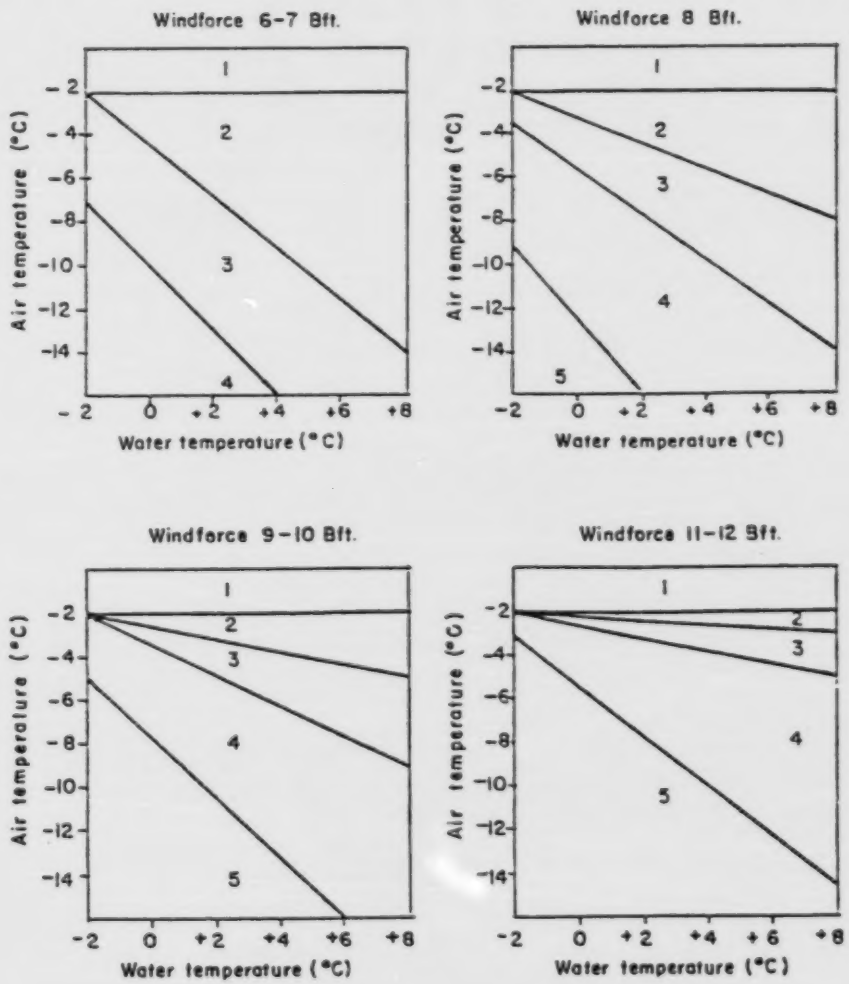
Diagrams have been produced which indicate the relationship between air and sea temperature and wind force, and the likelihood of a ship experiencing varying degrees of icing severity. The diagrams are reproduced as Figure 5 and were derived from 400 icing reports from German trawlers operating in the Barents Sea and in the waters off Iceland, Greenland and Labrador. They only indicate severity potential due to environmental conditions and do not take into account vessel design, speed, relative wind speed and direction, etc.

The reports on which the diagrams are based were from large trawlers, trawling at low speeds. However, it is considered that for smaller free running vessels, the icing rates would be higher (Mertins 1968) due to ship size and greater spray generation and increased speeds.

The diagrams clearly demonstrate the relationship between air and sea temperatures and wind force with respect to their influence on sea spray to cause icing in varying degree.

Stallabrass (1980) analysed icing reports from fishing vessels over two winter seasons operating in Canadian east coast waters, and plotted the effect of air temperature and wind speed on icing severity for vessels steaming at speeds of 4 knots and below and 5 knots or greater. These are shown on Figure 6 and 7 and indicate the degree of severity experienced. There is considerable scatter in the data points which is attributed to the non-scientific nature of the reporting of the amount of ice accretion and

FIGURE 5
MERTIN'S ICING DIAGRAMS



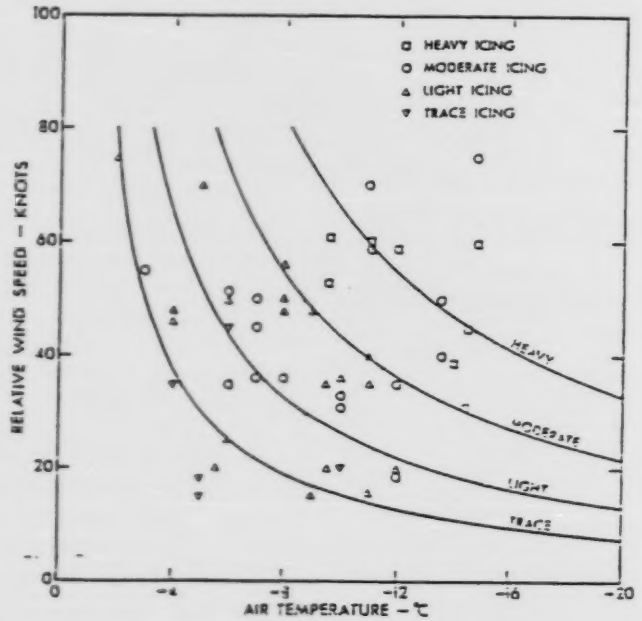


Fig. 6: Effect Of Air Temperature And Relative Wind Speed On Reported Icing Severity For Fishing Vessels At Low Speeds (4 Knots and Below)

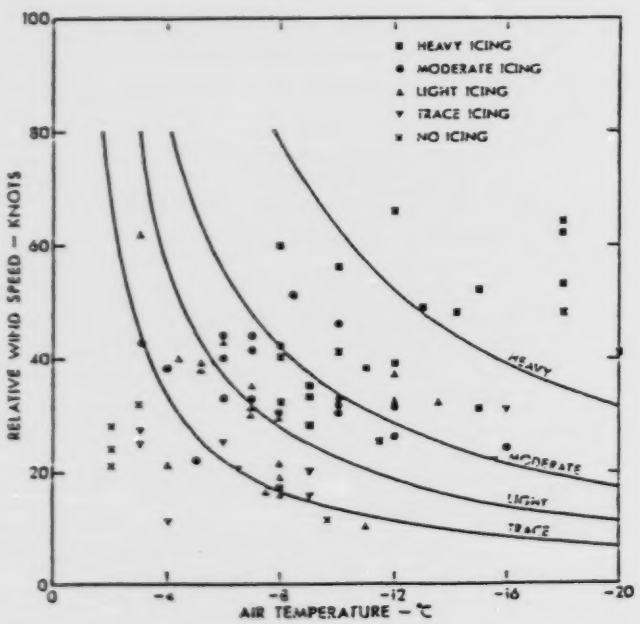


Fig. 7: Effect Of Air Temperature And Relative Wind Speed On Reported Icing Severity For Fishing Vessels Steaming At 5 Knots Or Greater

wave height, sea surface temperature, relative wind direction and vessel size. Stallabrass devised an approximation that when steaming at 5 knots or more, heavy icing may be expected if the product of the relative wind speed in knots and the air temperature in °C below 0°C is greater than 400, but when at speeds of 4 knots or below, the criterion for heavy icing increases to a product in excess of about 500. Both cases suggest that with products of relative wind speed and air temperature less than 200, the icing severity is of little or no significance.

Brown and Roebber (1985), carried out a more detailed analysis of icing severity from Canadian Coast Guard reports on Canadian east coast icing experience. The analysis was made from calculated values of icing rate and the IMO (Inter-Governmental Maritime Organisation) ice load criterion*. Based on that analysis, a statistical summary for each of the five east coast sub-regions was drawn up and is reproduced as Table 4. The percentage of heavy icing reports, i.e. icing rates greater than 23 cm/24 hours, show that vessels encountered greater frequency of severe icing conditions in the Gulf of St. Lawrence and Scotian shelf areas. However, reports indicate that N.E. Newfoundland shelf and Labrador Strait areas, suffer the greatest severity of icing. Bearing in mind that the icing reports are mainly from fishing vessels, the severity of icing reported may be related to weight of ice accumulated due to the longer voyages rather than related to rate of accumulation.

From their analysis of 960 ship icing reports spanning the years 1969 to 1984, Brown and Roebber reported that just over 550 contained information on icing duration. Typically, east coast icing duration is of the order of 15 hours, producing 5 to 6 cms of ice. The analysis also indicated, as shown on Table 5, that although the primary cause was sea spray, in a large percentage of cases it was associated with snow. Icing from freezing rain has not been considered to be a problem, and no cases have been reported of ice accretion thicknesses on ships in excess of 3 cm due to freezing rain.

An examination of the ship icing reports, a copy of which is reproduced as Figure 8, reveals that in many cases vital information is missing such as; heading of the vessel and/or direction and force of the wind, air and sea temperature. Weight of ice accreted is by estimate only. With respect to supply boats operating off the east coast, thirteen icing reports have been filed for the years 1982 to 1986. Invariably, the icing has been reported to have accreted over the whole ship and weight of ice estimated from 15 to 80 tons, reaching heights varying from 3 to 12 metres above the main deck. Ice thicknesses on deck have been estimated at from 2.5 - 7.5 cm with an average of 7.5 - 12.5 cm on rails, bulwark and wheelhouse fronts. One instance has been reported of lifeboats and liferafts which suffered severe icing, and in another, the radar scanner became iced up and had to be de-iced before the vessel's radar could be used. Of the 13 events reported, 2 took place in December, 3 in January and 4 each in February/March, with air temperatures ranging from -12°C to -3°C and sea temperatures from -1°C to +2°C. In most cases, snow contributed to the ice accretion. During the same time period there were five reports of

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* The I.M.O. ice load criterion is:

a) 30 kg/m^2 on exposed weather deck and gangways
b) 7.5 kg/m^2 for the projected lateral area of each side of the vessel above the waterline.

TABLE 4
SUMMARY OF ICING SEVERITY STATISTICS
OBTAINED FROM CANADIAN COAST GUARD SHIP
ICING REPORTS

Region (months in icing season)	ICING RATE (CM/24 HRS)			IMO CRITERION		
	No. of Obs.	Median	% Exceeding Icing Rate of 23 cm	No. of Obs.	Median	% Exceeding 2 x IMO
Gulf Of St. Lawrence (N - M)	48	3.0	12.5	78	0.5	7.7
Scotian Shelf (D - M)	160	4.0	20.0	275	0.5	6.5
Grand Banks (D - M)	115	4.0	10.4	206	0.5	7.8
N.E. Newfoundland Shelf (N - M)	152	3.5	7.9	206	0.5	9.7
Labrador Sea - Davis Strait (O - M)	28	3.0	7.1	37	0.5	8.1

TABLE 5

CHARACTERISTICS OF MARINE ICING AS DETERMINED FROM 960 VESSEL ICING REPORTS FROM THE EAST COAST OF CANADA

Season	Total Icing Reports	Spray Only %	Spray With Snow %	Spray With Fog %	Spray With Freezing Rain Or Freezing Drizzle	Atmospheric Icing Only %	Undetermined (Not Stated) %
1969-70	25	8.0	60.0	-	-	20.0	12.0
1970-71	74	13.5	67.6	-	1.4	4.1	13.5
1971-72	101	24.8	66.3	2.0	-	-	6.9
1973-74	79	21.5	53.2	-	-	2.5	22.8
1974-75	33	36.4	45.5	6.0	-	6.0	6.0
1975-76	124	17.7	71.0	-	1.6	-	9.7
1976-77	61	19.7	55.7	1.6	-	1.6	21.3
1977-78	159	19.5	69.8	-	-	-	10.7
1978-79	49	8.2	73.5	-	2.0	-	16.3
1979-80	51	7.8	70.6	-	-	3.9	17.6
1980-81	38	15.8	47.4	2.6	-	2.6	31.6
1981-82	77	15.6	59.7	1.3	-	1.3	22.1
1982-83	43	20.9	53.5	-	2.3	4.7	18.6
1983-84	46	32.6	47.8	-	-	6.5	13.0
Averages over 14 icing seasons (960 reports):		18.9	62.8	0.7	0.5	2.3	14.6

FIGURE 8
SHIP ICING REPORT FORM USED IN THE CANADIAN COAST GUARD VOLUNTARY ICING REPORT PROGRAMME

Transport Canada Transports Canada

SHIP ICING REPORT

PLEASE REPORT ON THIS FORM ANY INSTANCE OF ICE FORMATION ON VESSEL DURING VOYAGE. IF MORE THAN ONE OCCURRENCE OF ICING ON VOYAGE, USE SEPARATE FORM FOR EACH ENCOUNTER. IT IS IMPORTANT TO COMPLETE A FORM FOR EACH VOYAGE EVEN IF NO ICING OCCURS.

Name of ship: | Type of vessel:

Owner: | Home port:

DATE OF VOYAGE

Start: | Finish:

1. ROUTE OR AREA OPERATIONS –

State route or area – | Was icing encountered? – Yes ☐ No ☐

State where icing was encountered, give lat. & long., Decca or Loran fixes or distance and bearing from known point of land.

Give date and time (local) when icing commenced –

Date | Steaded

2. WEATHER CONDITIONS DURING ICING.

Weather (rain, snow, etc.) – | Wind (speed & direction) –

Sea state and wave height | Air temp. | Sea temp.

3. Speed | Heading

While ice was forming, was vessel steaming? ☐

heaving? ☐

dodging? ☐

other? ☐ Comment:

4. Severity of icing estimated as: ☐ Trace ☐ Light ☐ Moderate ☐ Heavy

5. INDICATE AVERAGE ICE THICKNESS AT VARIOUS LOCATIONS WHEN BUILD-UP IS GREATEST:

	0 - 1 in. 0 - 25 mm	1 - 2 in. 25 - 50 mm	2 - 3 in. 50 - 75 mm	3 - 5 in. 75 - 100 m	Greater than 5 in. - 100 mm Specify if desired
(a) Diameter of ice on forward rails		☐	☐	☐	☐
(b) Diameter of ice on other rails		☐	☐	☐	☐
(c) Diameter of ice on forward stay		☐	☐	☐	☐
(d) Thickness on main deck	☐	☐	☐	☐	☐
(e) Thickness on boat deck	☐	☐	☐	☐	☐
(f) Thickness on wheel house front	☐	☐	☐	☐	☐
(g) Thickness on bulwarks	☐	☐	☐	☐	☐
(h) Other specify	☐	☐	☐	☐	☐

6. To what height did ice extend on forward mast? Feet / Metres above main deck

7. Total weight of ice on vessel estimated as Tons

8. Was handling affected by icing?

Yes ☐ No ☐

Comments such as rolling time and amount of heel would be helpful.

9. Additional comments:

COMPLETED FORMS SHOULD BE MAILED TO: LOW TEMPERATURE LABORATORY, DIVISION OF MECHANICAL ENGINEERING, NATIONAL RESEARCH COUNCIL, OTTAWA, ONTARIO K1A 0R6

BS-0273 (11-73)

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tanker icing with estimated accretion of between 75 and 200 tons, with flying bridge, pipelines and manifolds completely iced up. These events occurred during the months of January and February.

While in a number of instances, vessels have had to stop and de-ice to prevent dangerous ice accumulation, only one case was recorded where ship handling was affected by icing. This occurred on the CCG D'IBERVILLE while on a voyage off the east coast in February 1980 when the vessel reported an accumulation of ice estimated at between 500 and 600 tons. Ice was estimated on most areas as being between 15 cm - 30 cm thick with 15 cm - 45 cm on the wheelhouse front. The vessel was iced up to a height of 10 metres above the main deck. Air temperature was -13°C and sea temperature 1°C. The exact effect on ship handling was not reported, nor was any information given on steps taken to de-ice the vessel.

4.3 Ship Operator Experience

Discussions with Canadian ship operators and ship's masters whose vessels trade in Canadian waters, confirm that vessels ice up regularly in the Great Lakes, Gulf of St. Lawrence and off the Canadian east coast.

Great Lakes vessels regularly experience severe ice accretion, with the forward section of the ship particularly affected. It is common-place to have all foredeck equipment totally iced up, hatches frozen, a build up of ice on deck and considerable ice accretion on rigging, rails, and ladders. Superstructure icing is a regular feature but seldom have lifeboats or liferafts been affected. No problems have been reported with respect to ice accretion on fuel oil filling or vent pipes.

Icing up of Canadian tankers, which trade to the Gulf of St. Lawrence and east coast oil terminals is common. One owner reported that on tankers with a 7 ft. freeboard loaded, winches, windlass and anchors became a solid mass of ice. The forward half of the decks have iced up and handrails have grown in diameter from 5 cm to 30 cm due to ice accretion. Superstructure icing has occurred up to the first accommodation level above the weather deck. Lifeboats and liferafts have also become severely iced up on occasions.

Another tanker owner reported instances when his vessels had been completely covered in ice from forward to aft, and lifeboats and liferafts were totally iced up as were fire hydrants. In a worst case, off the coast of Nova Scotia, the foremast and flying bridge collapsed due to the weight of accreted ice.

A former master of an oceanographic research vessel related an event 100 km south east of St. John's, Newfoundland when his vessel had to heave-to throughout the night to reduce ice accretion due to spray. On arrival in St. John's the ship was virtually encased in ice which extended to the top of the mast. All deck equipment and outside passageways were thick with ice as was the ship's superstructure up to the height of the bridge windows. Lifeboats, davits, wires and sheaves were completely encased in ice as were the liferafts. Figures 9 to 16 graphically

Fig. 9: Portside Winch And Superstructure Looking Aft

Fig. 10: Looking Forward From Port Passageway

Fig. 11: Ships Crane, Wires And Deep Sea Winch Looking Aft

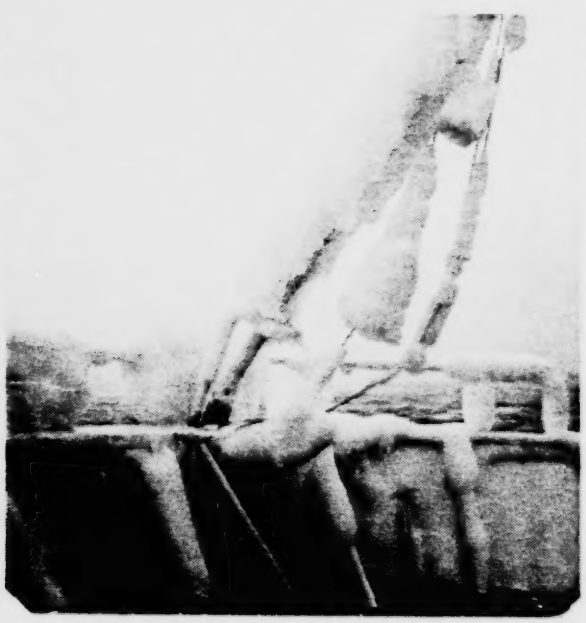


Fig. 12: Jackstaff and Halyards

Fig. 13: De-icing Starboard Crane And Superstructure

Fig. 14: Windlass, Crane And Wires

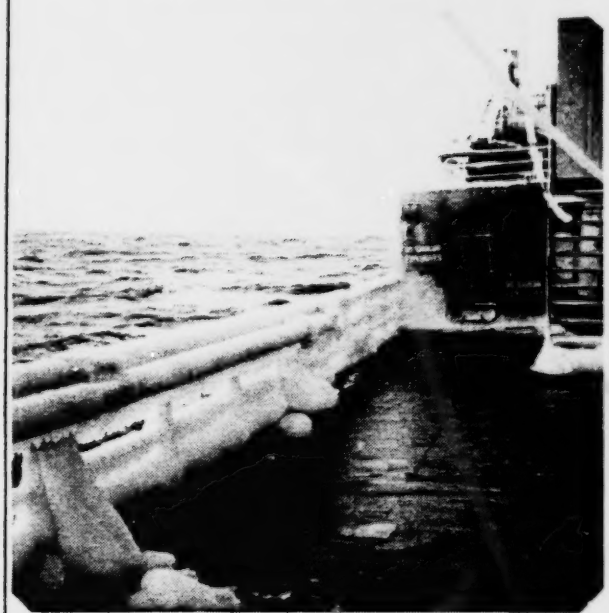


Fig. 15: Port Side Midships - Iced Rails With Ice Free Deck

Fig. 16: De-Icing Windlass

illustrate the extent of the ice accretion. Although the weight of ice was not estimated, the particular vessel was built to withstand up to 300 tons of icing without danger to stability. Additional illustrations of the extent to which vessels plying the Canadian east coast can suffer ice accretion are shown by Figures 17 to 19.

Apart from the statistical evidence presented in Section 4.2 it is abundantly clear from the personal experiences of ship operators and masters, that the icing of vessels which operate off the Canadian east coast during winter, may endanger both ships and their crews. Deck and lifesaving equipment and fire hydrants have been rendered inoperable and risk of accidents to ships crews is increased due to icing of decks, ladders and handrails. This is a particular danger on supply vessels, when the crew are handling wires and working cargo in a seaway alongside a rig or platform. Furthermore, operational delays can arise due to inability to operate mooring winches or cargo gear, if a vessel arrives in port in an iced up condition.

It is of interest to note that an analysis of serious injuries of personnel on board Norwegian fishing vessels between 1961 and 1975 shows that 22% of all injuries were caused by slipping and falling due to ice (Jorgensen 1982).

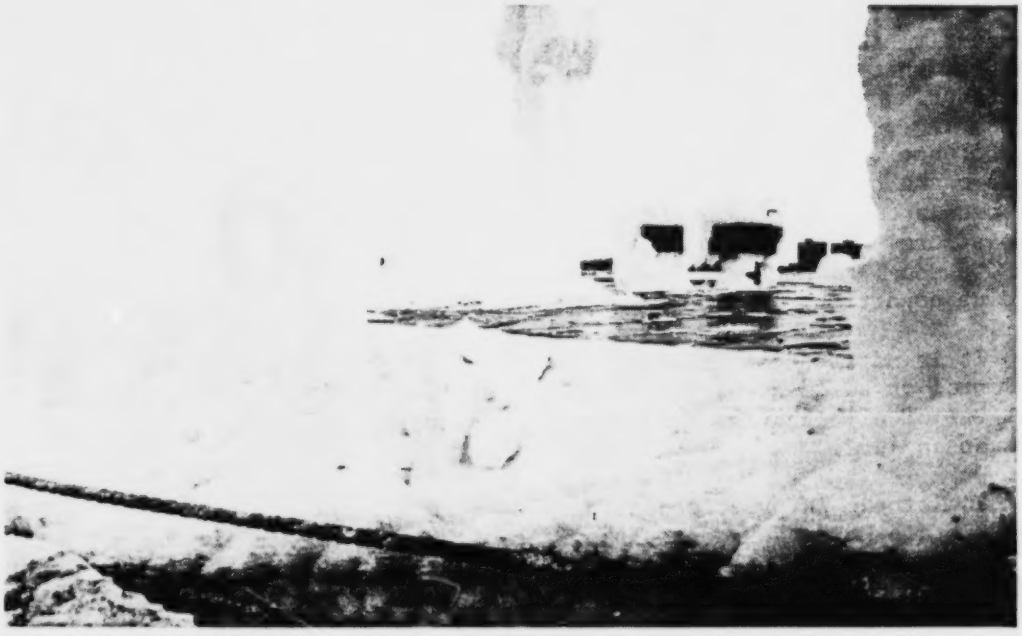
Additional information on icing dangers was obtained in conversation with Captain Marozove, General Manager of Morflot, Montreal, who has had considerable experience of icing on board Russian ships. He advised that icing had not been experienced until wind force exceeded Beaufort 5, and from his service on board various ship types, the greater the freeboard, the less was the icing. In gale weather in the Baltic he had experienced a build up of 50 cms of ice on deck. On tankers and cargo vessels, bulwarks, foredeck and equipment iced up completely. In particular, in severe weather he had experienced ice accretion over the entire ship, including lifeboats and davits on the boat deck. Derricks, cranes and wires were thick with ice, hatches were frozen and deck cargo was covered in ice. On container ships, icing has extended over deck containers to a height of about 9 metres. Superstructure icing was common, and he has had to stop his ship to reduce further build up, and have the crew on deck to break up the ice. In many cases operational delays had been considerable.

He reported that no statistics are available in Russia of ship icing in general. All investigative work carried out has been on fishing vessels which are most at risk because of their low freeboard.

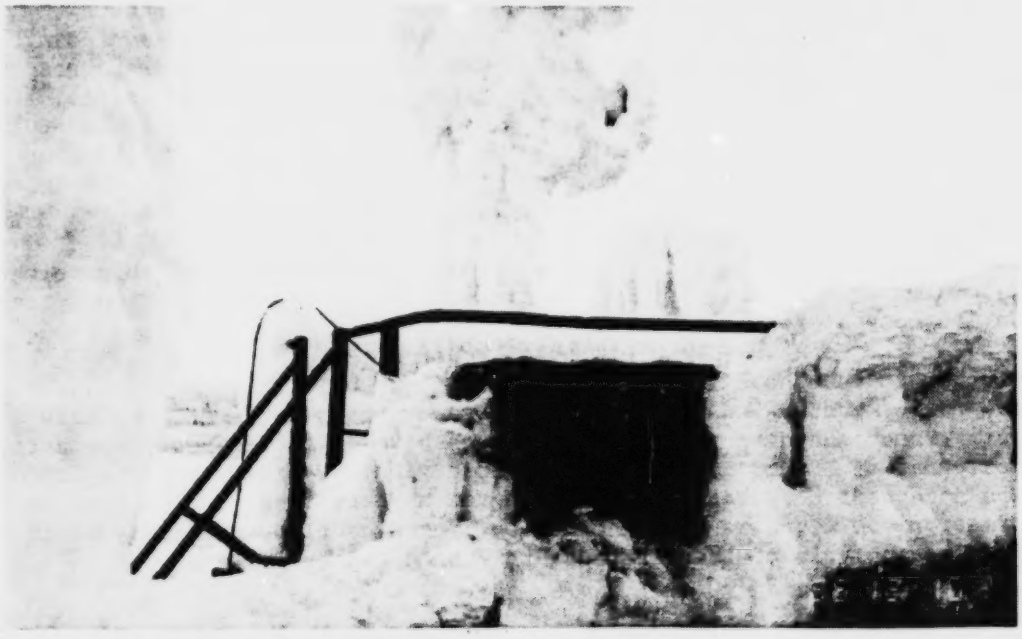
Other sources have reported severe icing on bulwarks, forecastle decks, rails, masts, and superstructures, deck equipment and cargo gear (Tabata; Panov; Bandarson). The literature however lacks quantitive data. A Russian study (Panov 1976) analysed and divided 494 icing reports into groups dependent on where the icing had taken place in each case, but no information was given as to the extent of ice accretion, or the types of ship. The analysis of these reports is reproduced as Table 6.

FIGURE 17

ICING ON A BULK CARRIER
GULF OF St. LAWRENCE. DEC 9 - 12 1986



(a) ICE BUILD-UP ON VENTS AND HATCH COAMING



(b) ICE BUILD-UP ON MAST AND BOAT DECK

SOURCE : FEDNAV LTD.

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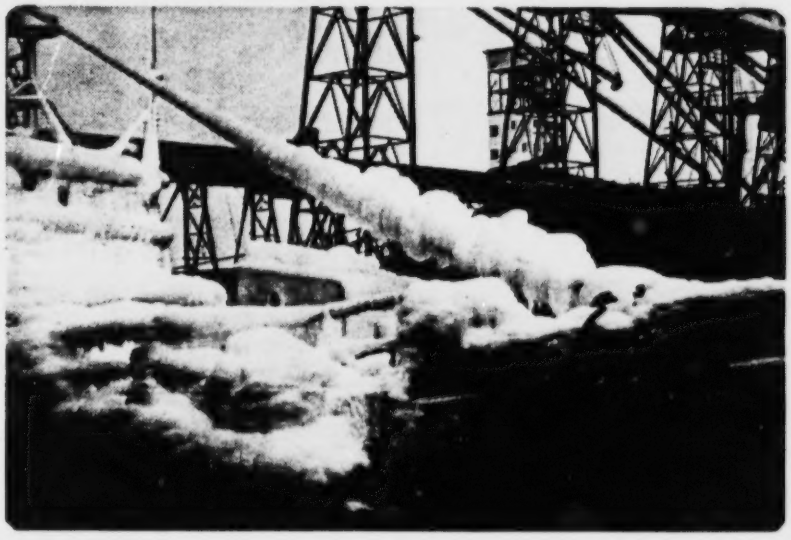
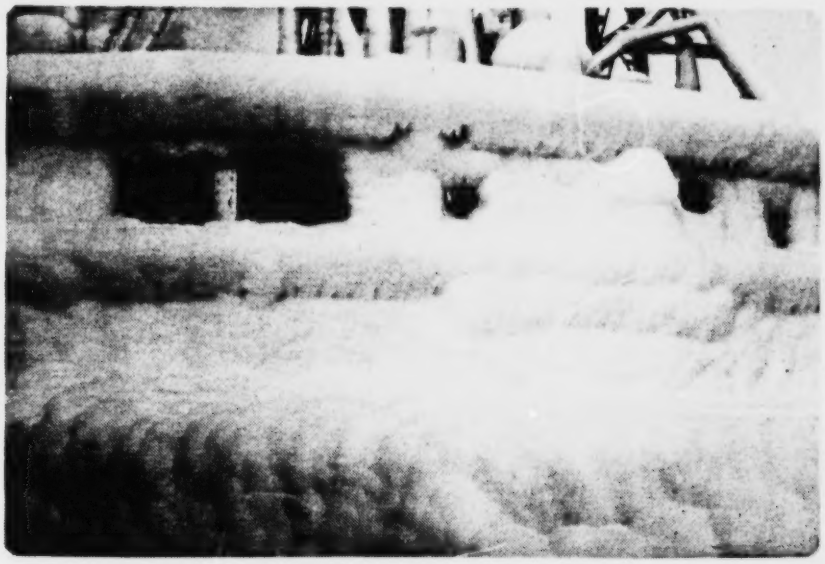
FIGURE 18

ICING OF STERN TRAWLER
JAN 26 - 27 1972



(a) ICE BUILD-UP ON RAILS, ANCHORS AND FORESTAY



(b) ICE BUILD-UP ON WHEELHOUSE FRONT

SOURCE : N.R.C.

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FIGURE 19

ICE BUILD-UP ON GOVERNMENT SURVEY SHIP
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SOURCE : N.R.C.

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Table 6

Frequency Of Icing Of The Main Ship Structures

Structure	Number Of Cases
Side	8
Forecastle	14
Forecastle, decks	119
Rigging, mast and spars	12
Superstructure and superstructure decks	91
Forecastle, deck, rigging, masts and spars	86
Forecastle, decks, rigging, superstructure	150
Stern	7
Whole ship	7

5. THE IMPORTANCE OF ICING ON SHIP STABILITY

5.1 The Present Regulatory Approach

For the vessel types which are being considered in this study the only Canadian Shipping Act (CSA) regulations pertaining to stability are those which apply to:

a) Large Fishing Vessels (LFV) - which are vessels over 24 metres in length.

b) Offshore Supply Vessels (OSV) - which are over 24 metres but under 100 metres in length.

Table 7 shows the weight of accummulated ice in kg/cm^2 permitted under CSA regulations and the IMO ice load criterion.

Table 7

AREA	CSA		IMO
	LFV	OSV	FV
Total Deck Areas	54	54	30
Superstructure and Deckhouse Fronts, Sides, and Inside of Bulwarks	37	37	7.5
Guardrails, Stanchions, Coaming, etc.	78	78	7.5 + 5%
Rigging, Masts, etc. up to 6.1 m Above the Main Deck	48	48	7.5 + 5%

It would therefore appear that for those vessels of the Hibernia fleet which are Offshore Supply Vessels the Canada Shipping Act Regulations will apply, but for the remaining vessels, including the standby vessel, ice clearing vessel, diving support vessel and shuttle tankers, no requirement exists to consider icing in the stability calculations.

5.2 The Effect Of Ship Size

Ship size can have a major effect on ship stability and therefore on the ability of a ship to withstand safely the accretion of ice. Before reviewing the effect of various ship parameters and assessing the specific vessels planned for the Hibernia operation, it is important to understand the fundamentals of ship stability. A standard reference for this subject would be "The Principles of Naval Architecture, SNAME 1967" or the "Stability, Subdivision, and Load Line Standards, issued by the Canadian Coastguard - Ship Safety Branch". Notwithstanding the detailed discussion

of the theory of ship stability which is available in those references, the following discussion reviews the important aspects to identify where the ship size parameters play a part.

The metacentric height (GM) is the fundamental measure of ship stability. This dimension measures the distance from the ship's vertical centre of gravity to the position of the transverse metacentre. This metacentre position is highly dependent on the ship's shape and size and is obtained by adding to the vertical centre of buoyancy the distance between the point and the metacentre. These distances can be expressed by the equation:

$$GM = KB + BM - KG$$

Where: KB = vertical centre of buoyancy above the keel
BM = metacentre above the vertical centre of buoyancy
KG = vertical centre of gravity above the keel

The value of KG is a function of ship weight and of the location of the centre of each component of that weight. While this value can be shape dependent it is more often related to the design of tank space, machinery spaces and accommodation. The value of KB can be shape dependent but is most effected by 'draft'. The value of BM is effected in several ways by ship size and shape. To illustrate, the value of BM is calculated by the following equation.

$$BM = \frac{I}{V}$$

Where: I = transverse moment of inertia of the waterplane
V = volume of displacement of the hull

If in place of I and V the dimensional parameters which are used to calculate each value are substituted it is possible to see quite clearly the influence each dimension might have on the value of BM and hence on ship stability.

$$BM = \frac{I}{V} = \frac{L.B^3/12}{L.B.H.Cb} = \frac{B^2}{12.H.Cb}$$

Where: L = ship's length
B = ship's beam
H = ship's draft
Cb = ship's block coefficient

It can be seen from this that stability is unaffected by the ship's length but is proportional to the square of the beam, and inversely proportional to the draft and block coefficient. In addition, ship depth directly affects the position of the vertical centre of gravity, inversely effecting the stability. Freeboard, the distance from the waterline to the weather deck, increases the residual buoyancy which directly effects the 'range of stability'.

The vessels which are required for the Hibernia project are shown diagrammatically on Figures 22 to 27. The vessels are shown in silhouette at the same scale to highlight the difference in size. The dimensions of each vessel are provided in Table 8.

Table 8

Dimensions Of Proposed Hibernia Offshore Vessels

VESSEL	L (m)	B (m)	D (m)	H (m)	Cb
1. Offshore Supply Vessels (OSV)	80	13	7	5	0.5
2. Ice Clearing Vessel (ICV)	92	19	13.5	9	0.5
3. Diving Support Vessel (DSV)	105	19	11	7	0.5
4. Well Workover Vessel (Monohull)	Dimensions Similar To DSV				
5. Shuttle Tankers					
- 120,000 dwt	260	40	21.5	16.5	0.8
- 77,000 dwt	240	35	19.5	13.2	0.8

Mobil Oil Canada Ltd. have designated the Ice Clearing Vessel to act as the Standby Vessel, although this vessel may be supported in this role or substituted by an Offshore Supply Vessel.

It is clear from the table that the shuttle tankers will not be effected significantly by ice accretion. The ships displacements are very large compared to the potential weight of ice, and their beams are substantial. The ships which require closer inspection are the OSV's, ICV and DSV. Of these, the OSV's are the most critical since:

a) The OSV's have the lowest displacement and are therefore more effected by the weight of ice.

b) The OSV's have the lowest freeboard, resulting in a reduced range of stability.

c) The ICV has a larger beam and draft than the OSV's, resulting in an increase in the value of BM of about 20%.

d) The DSV also has a larger beam and draft than the OSV's, resulting in increase in the value of BM of about 50%.

The metacentric height of the ICV and DSV will be adversely effected by the larger depth, raising the value of KG, but this will be offset by the increased draft which raises the value of KB. While these two factors may not completely cancel out, the remaining differences will be small in comparison to those in a) through d) above.

5.3 Validity Of The Regulatory Requirements

The experience of ships which operate on the Grand Banks of Newfoundland, if properly documented, should be a guide as to the validity of the present regulations for the proposed Hibernia support vessels. This experience is documented in the Transport Canada Ship Icing Reports. These reports are preformatted and organised to permit the ships officers to provide a range of information; such as the location and thickness of ice onboard, and an estimate of the weight of the ice. Unfortunately, although many reports have been completed and forwarded to Transport Canada, the quality of information is often poor or too qualitative to allow conclusions to be drawn.

However, it has been possible to find reports which do provide hard data or at least estimates of the quantity of accummulated ice. Particularly with respect to the Offshore Supply Vessels, which are the most susceptible to reductions in stability due to icing, 13 reports were found and analysed. The estimated weight of ice ranged from 15 to 80 tonnes with a mean value fo 45 tonnes. Of the 13 ships, 3 had icing weights of 75 tonnes or greater.

To assess the validity of the present regulatory approach an example calculation has been performed, for an Ulstein 708 OSV, using the weight per square metre for each part of the ship, as defined in the Canada Shipping Act regulations. The results indicated that 85 tonnes of ice would be accummulated at a mean height of 10.72 m above the keel. This weight is similar to the highest values found from the Ship Icing Reports. Applying this weight of ice to the worst loaded condition for this vessel (full deck load arrival) the ice onboard reduces the GM from 1.24 m to 1.21 m, leaving the vessel with acceptable stability.

This exercise shows that for the most problematic vessel in the Hibernia fleet (with respect to stability) the present Canadian regulations are valid. Despite the comparison which shows these regulations to be considerably more demanding than IMO requirements, the available statistics for Canadian waters, although sparse, seem to justify the conservative approach. Similarly, it would appear that the effect of icing on stability should not be of concern for the Hibernia fleet.

6. POTENTIAL FOR ICING OF HIBERNIA VESSELS

6.1 General

A variety of vessel types are forecast to service and support east coast offshore oil and gas exploration and production. Under consideration to support Hibernia production development are:

- logistics/supply boats
- ice clearing and field support vessel
- diving support vessel
- well workover vessel
- shuttle tankers

The vessels will operate year round and will therefore be exposed to ice accretion during the winter months. The design and operational functions of these vessels will determine to a large extent, the degree of ice accretion they may experience.

In response to questionnaires sent out by Brown & Roebber in connection with their 1985 report, the consensus of east coast oil operators was that while atmospheric and sea spray icing did occur on workboats and to a much lesser degree on drilling units, it had never posed a major problem to operations. Nevertheless, delays had been experienced related to the icing of workboats and it was anticipated that icing of those vessels would be a continuing problem.

6.2 Icing Patterns

Researchers agree that the extent of sea spray icing likely to be experienced by a ship under a given set of meteorological conditions is affected by such factors as vessel shape, size, speed and heading relative to the wind, the wind force, wave height and sea state (Stallabrass, Jorgensen, Yerokhen, Vasil'Yeva, Bandarson).

As referred to in Section 2.4, the size of ship has a great influence on the icing pattern, mainly because of the ship's freeboard. Bigger ships have a larger freeboard, with decks, masts, rigging and superstructures at a higher level above the sea. Icing on these vessels is considerably less than on smaller ships because of the reduced intensity of spray with height (Brown & Roebber). Freezing rain, however, can result in significant accumulations of ice high on superstructures and in some cases result in serious instability. Reports have been received from ships that the turning mechanisms of radar scanners have failed due to the heavy accumulation of ice. Tests have also shown that there is a very high loss of radar performance caused by only 1/4 to 1/2 inch of ice (Ward 1970).

Depending on superstructure height, there is also the possibility of icing up of bridge windows which would interfere with the safe manoeuvring of a ship, and any obstruction on deck or superstructure, such as windlasses, winches, lifeboats, davits, cranes, etc. will act as catchment zones and become a source of ice accretion.

Flooding of open decks by wave action is generally not a source of ice. Normally the flushing action of waves will wash away any ice that is in the process of forming. However, depending on the temperature of sea and air, and the frequency of waves, a film of ice may form. Ice will certainly form on decks if drainage holes or freeing ports are blocked, or if water becomes trapped among deck cargoes.

6.3 Logistics/Supply Boats

The extent of bow and bulwark flare influences the amount of sea spray likely to come aboard a vessel independently of environmental conditions. Figure 20 is typical of the spray pattern likely to be experienced by supply boats.

FIGURE 20 SUPPLY BOAT IN HIGH SEAS

Some supply vessels have been designed and built with minimum flare, but North Sea experience has led to designs which take account of the moderating effect of bow flare on spray.

Rigging, which is an area of high ice accretion is minimal on supply boats, which reduces the risk. However, ice accretion on radar scanners is probable and will cause serious degradation in radar performance. This will prove to be a handicap in the operation of the vessels proposed for Hibernia, and apart from the navigational aid aspects of radar, will particularly affect the iceberg detection capability.

Except for the forecastle, the deck area of supply vessels is generally free of equipment other than anchor handling/towing winches. The large flat deck area aft, which is used to carry deck cargo is frequently awash in heavy seas which reduces the danger of icing. Nevertheless, given the appropriate conditions, decks will ice up, become slippery and present a danger to any ship's personnel who have to work in the area.

Supply boats have a very short foredeck on which are located anchor handling and mooring winches which are protected from spray, to a degree, by high bulwarks. Nevertheless, if freeing ports become blocked, severe icing up can occur. Water may also become trapped by cargo on the large aft deck and cause further ice accumulation.

Ice accretion will occur on handrails and superstructure and vision from the bridge windows may be impaired thus affecting navigation. Lifeboats and davits, if situated at forecastle or bridge deck level, are likely to suffer severe icing which may render them useless in emergency. Inflatable liferafts in fibreglass containers in exposed positions will be affected, as will hydrostatic release mechanisms if fitted. Fuel oil and other cargo tank vent pipes may also become blocked by ice.

Proposed Hibernia supply boats will typically be fitted with a fast rescue craft and launching crane, firefighting monitors, iceberg towing equipment and a special crane for use in conjunction with a rescue recovery net. All of that equipment will be in danger of becoming inoperative due to severe icing.

The functions of supply boats necessitate regular transits between production (or drilling) platforms and occasional stand-by duties in the vicinity of platforms regardless of weather. Additionally, supply boats often must endure severe weather merely waiting in the vicinity of a rig or platform before being able to discharge their cargo. It follows that during the winter season, given environmental conditions conducive to icing, these vessels, their equipment and personnel will be unable to function as required unless special consideration is given in ship design to minimise the effect of ice accretion.

Working operations alongside a rig or platform present the greatest risk of injury to personnel who have to work on the open deck mooring or handling cargo. Often these operations take place in a heavy seaway, with the vessel heaving and pitching, when even the slightest degree of icing will create a danger of slipping and falling.

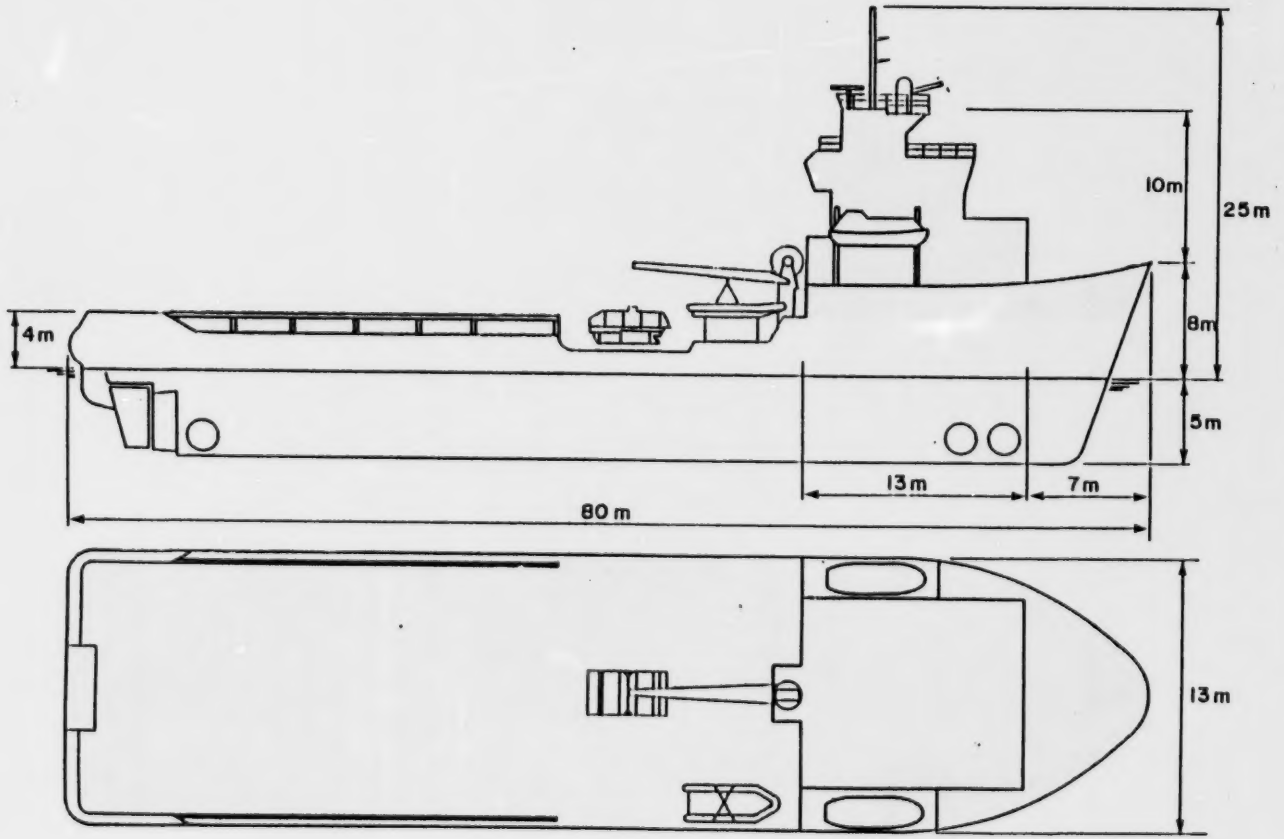
Of all offshore vessels, supply boats are probably the most at risk from instability. Due to their light displacement and relatively high centre of gravity, added weight of any significance above the waterline due to ice accretion could seriously endanger the vessels. With their low freeboard, water can readily fall on deck and become trapped within the deck cargo, especially if the vessel is carrying pipes. This will increase topside weight and have free surface effects which, when added to superstructure icing will increase the instability hazard. Figure 22 illustrates the areas most likely to suffer ice accretion.

6.4 Ice Clearing and Field Support Vessel

This vessel will be larger than the supply vessels and apart from ice clearing duties, will act as the platform standby vessel and provide major emergency support to the production facilities. It will also assist the shuttle tankers by deploying their mooring lines to the floating cargo loading facility.

The vessel will be equipped in substantially the same manner as the logistics/supply boats, but to a greater extent. The vessel will have a much longer foredeck than the supply boats, and the anchor and mooring winches will be more exposed to spray icing. It will also have a higher

FIGURE 21
- LOGISTICS SUPPORT VESSEL -
TYPICAL PROFILE AND DECK PLAN



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superstructure which, due to its more extensive surface area, will increase the likelihood of greater ice accretion. As the vessel will have a long exposed aft deck, ice may build up if water is trapped within or around the cargo to be carried. Because its functions demand that it be on station much longer than supply boats, it is possible the vessel will experience greater ice accumulation unless steps are taken by the crew to de-ice the vessel.

Stability will be reduced due to icing, the extent depending on the severity and height to which the ice accretion extends. However, for the same weight of ice, the vessel will be less affected than the supply boats due to its greater freeboard, beam and draft.

The multi-functions of this vessel which will require considerable crew activity on deck, include anchor handling, cargo loading/discharge, and routine shuttle tanker mooring assistance. All of these will expose the ships personnel to potential injury if the vessel is iced up. Operational difficulties will also arise if the vessels exposed deck equipment become covered in ice.

A particular function of this ship will be emergency duties, and its capability in this direction will be at risk if its lifesaving and firefighting equipment become inoperable due to ice.

Figure 22 indicates the areas which will most likely be affected by ice accretion from either sea spray or atmospheric sources.

6.5 Diving Support Vessel

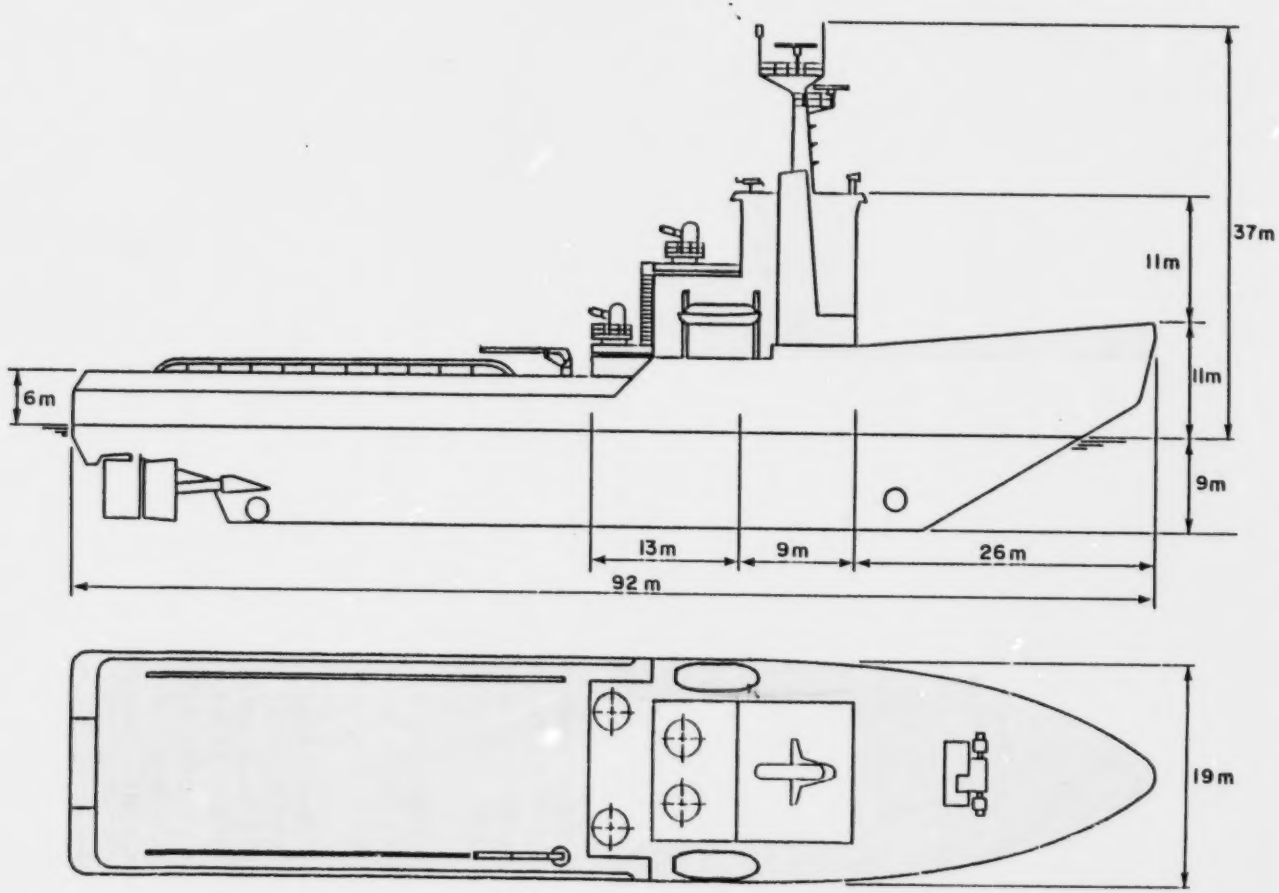
The diving support vessel will provide diving equipment, spares and supplies and serve as a base for divers to carry out inspection, maintenance and repairs on all sub-sea equipment.

The vessel will be similar in size to the ice clearing vessel, but typically the superstructure will be well forward and surmounted by a heli-deck. A large crane, fire monitors and decompression chambers for diving crews will be located on the aft deck. The ship will be fitted with an anchor handling and mooring system, with anchor winches fitted forward and aft. Windlass and winches will be potential ice accretion areas as will the crane, lifesaving and firefighting equipment. Severe icing will have an adverse effect on these items of equipment which are crucial to the vessel's operation.

The superstructure and the underside of the overhanging heli-deck are also potential ice collectors, although it is unlikely (but possible), that the heli-deck itself will experience sea spray to a significant extent, due to its height above the sea surface. Nevertheless, helicopter operations would require to be suspended if icing were to occur on the landing area.

Because of the necessity of crew members to work on the large open aft deck, conditions will be difficult and dangerous if even a thin film of ice forms at sub-zero temperatures.

FIGURE 22
ICE CLEARING AND FIELD SUPPORT VESSEL
TYPICAL PROFILE AND DECK PLAN



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During diving operations, station-keeping is important since the vessel must be able to maintain its position over the diving area. When on station and diving operations are under way, as there will be no ship generated sea spray, the extent of ice accretion will be dependent on spray due to wind force and wave height and ice from atmospheric sources. Any degree of icing will reduce the ship's stability but is unlikely to have any appreciable effect due to its displacement and low centre of gravity.

Figure 23 indicates the areas which will most likely be affected by ice accretion from sea spray, although it has to be borne in mind that if atmospheric icing is experienced, it will occur over all areas of the ship.

6.6 Well Workover Vessel

Well workover vessels may be of small semi-submersible or monohull construction. Their function is to service sub-sea wells and undertake well stimulation operations, and for this purpose carry large quantities of stimulation fluids. High pressure units are required to pump a complex variety of well stimulation fluids, but these units are normally installed undercover and are not exposed to the elements.

Heavy lift cranes are installed on deck to lift equipment from the sea bed. Well workover vessels are commonly fitted with a moonpool as diver assistance is required for most of the work performed under water. The handling of production tubing and marine risers is also carried out over the moonpool using the deck cranes in conjunction with a modified derrick arrangement. Clearly, workover operations will be impossible if the cranes become inoperable due to serious icing.

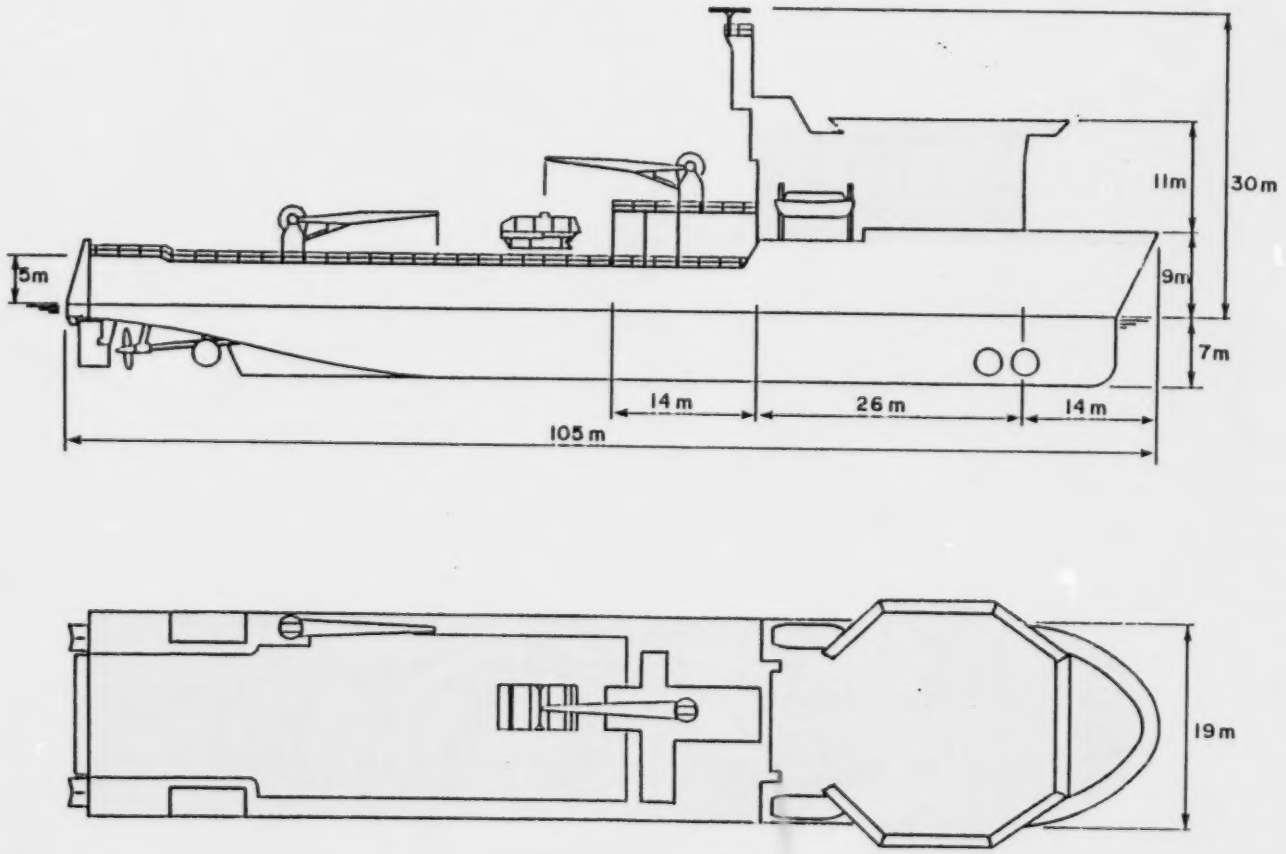
As it is necessary to remain stationary over the work area, workover vessels are fitted with dynamic positioning systems but also have a four point mooring capability. This requires the installation of deck winches to handle the anchors and cables which will be subject to ice accretion.

In addition to their susceptibility to icing due to the obstruction of deck equipment, well workover vessels are often fitted with helicopter decks which will add a further area of ice accretion potential.

If the vessel is of monohull design, when on station, ice accretion, if it occurs, will most probably be from atmospheric sources. Icing from sea spray is likely to be limited, and will be dependent on wave height and wind force. As much of the work of crew members take place on deck, there will be an ever present danger of injuries if ice is present in any form on decks, ladders and outside alleyways. Fire hydrants and lifesaving equipment will also be at risk from ice accumulation.

If the vessel is of semi-submersible design, in addition to atmospheric icing, the structure will experience icing due to sea spray, especially on columns, struts, and on the underside of the platform. Ice accretion can also add substantially to deck weight and will affect mooring winches, cranes, superstructure, handrails and ladders, helideck, fire and lifesaving equipment. Personal safety will be compromised, deck equipment may become inoperative and vessel stability put in jeopardy.

FIGURE 23
- DIVING SUPPORT VESSEL -
TYPICAL PROFILE AND DECK PLAN



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Figures 24 and 25 are typical of semi-submersible and monohull construction and show the likely areas of ice accretion.

6.7 Shuttle Tankers

Shuttle tankers will be used to transport crude oil from Hibernia production platforms to east coast terminals. They will connect up at the bow to an articulated arm located distant from the platform.

Although subject to the same ice accretion conditions as other offshore vessels, the effect on stability will be much less severe since they will have a greater freeboard.

Nevertheless, from ship icing reports and tanker operators, experience indicates that tankers operating off the east coast can suffer extreme ice accretion, especially when loaded. Windlass, mooring equipment, decks, pipelines and loading/discharge manifolds are all subject to ice accretion from sea spray as are the bow, handrails and flying bridge.

Firefighting monitors located on the flying bridge, fire hydrants and lifesaving equipment have all been known to ice up completely. Lifeboat davits, lifeboats and liferafts have become encased in ice and would have been incapable of being used if an emergency had arisen.

Unlike conventional tankers, the shuttle tankers will have a bow loading station with appropriate mooring and hose handling winches and a midship cargo discharge manifold. Although it is unlikely during a ballast voyage to the loading platform, if icing of the foredeck has occurred affecting mooring and hose handling winches, not only will there be considerable delay before loading operations can begin, it will also present a danger to the crew members involved in the mooring and hose connection operations.

Depending on their size, shuttle tankers when loading could be alongside the loading platform for up to 16 hours, or longer if the vessel has to stand off due to storm conditions. Depending on the weather, ice accretion might then occur due to waves striking the ship, from wind generated spray and/or freezing rain or snow, and a particular danger could arise of pressure/vacuum valves icing up. These valves could ice up whether the vessel is stationary or under way. When on passage loaded, if there is continuous flooding of the deck by sea water, it is probable it will prevent any substantial accumulation of ice except in isolated areas from where it cannot drain away.

Past reports, however, clearly indicate that in severe environmental conditions, there could be a substantial accumulation of ice on the main deck, on piping systems and discharge manifolds. Nevertheless, relative to the deadweight of the shuttle tankers which could be from 77,000 to 120,000 dwt, any ice accumulation will have little effect on their vertical centre of gravity and stability.

Figure 26 is an outline diagram of a typical design of shuttle tanker, on which is indicated probable icing areas.

FIGURE 24
WELL WORKOVER VESSEL
(SEMI-SUBMERSIBLE)

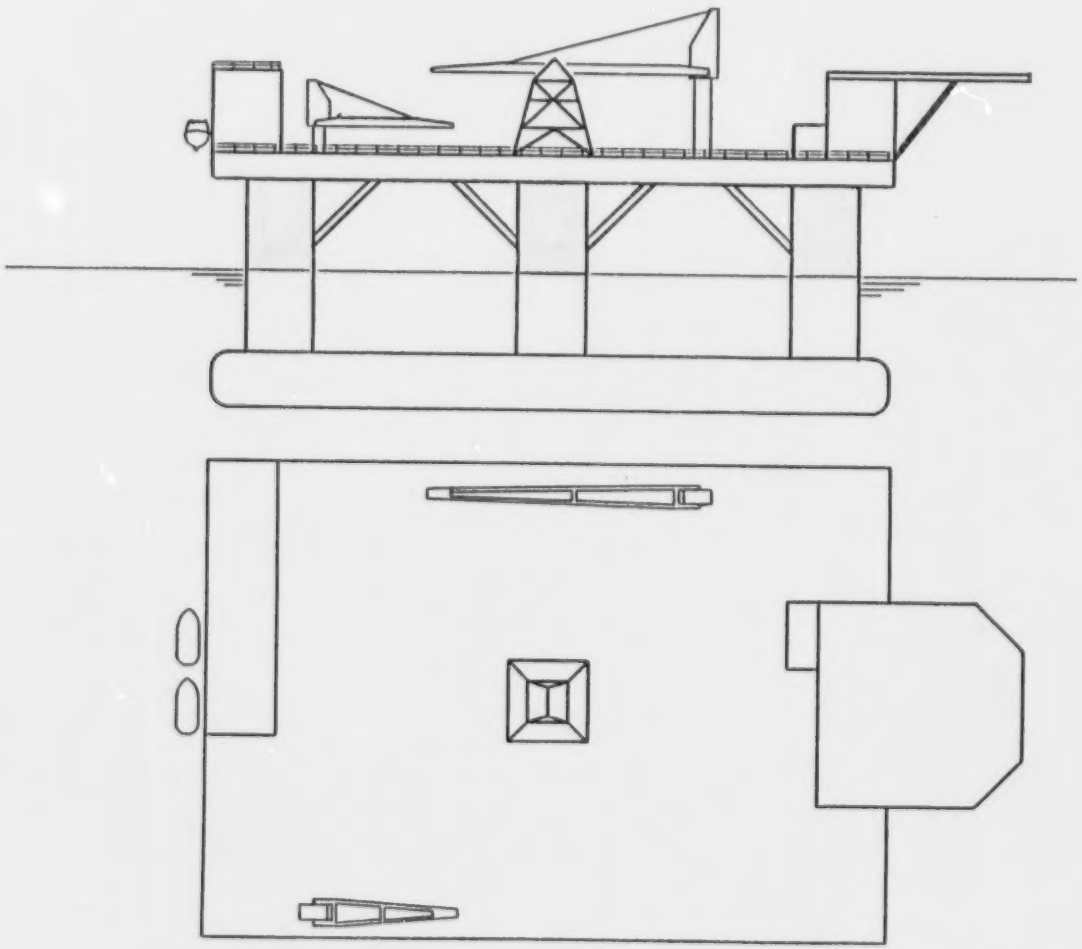

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FIGURE 25
WELL WORKOVER VESSEL
(MONOHULL)

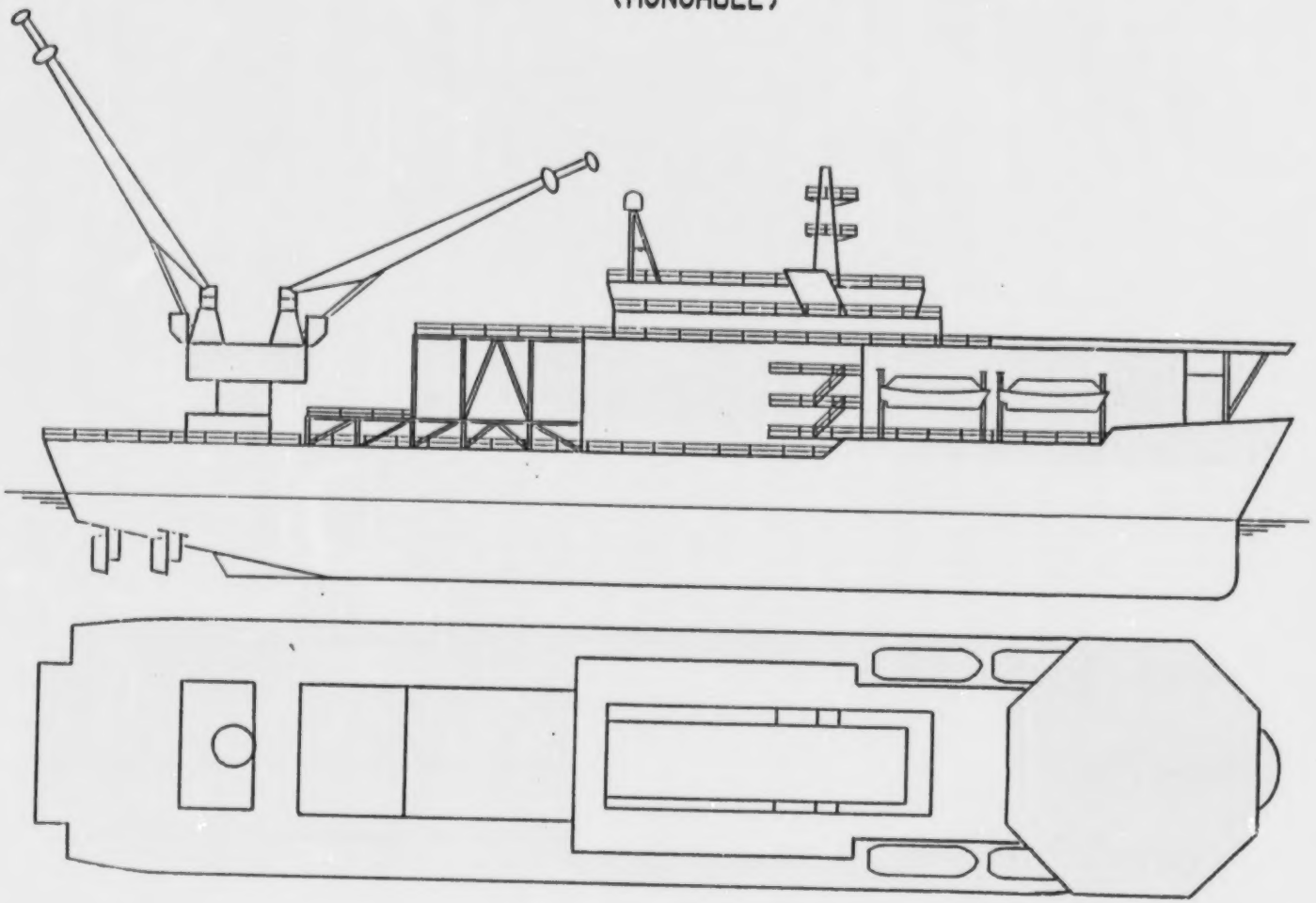

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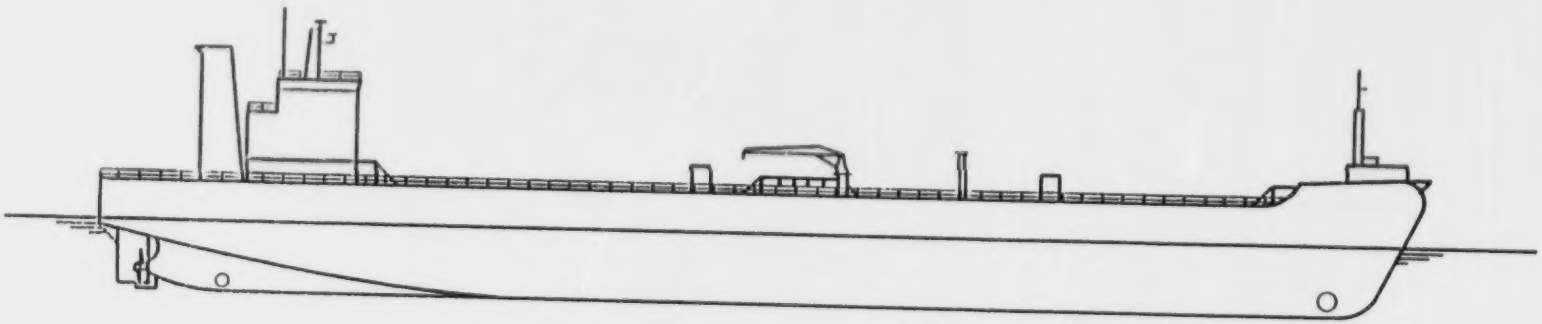
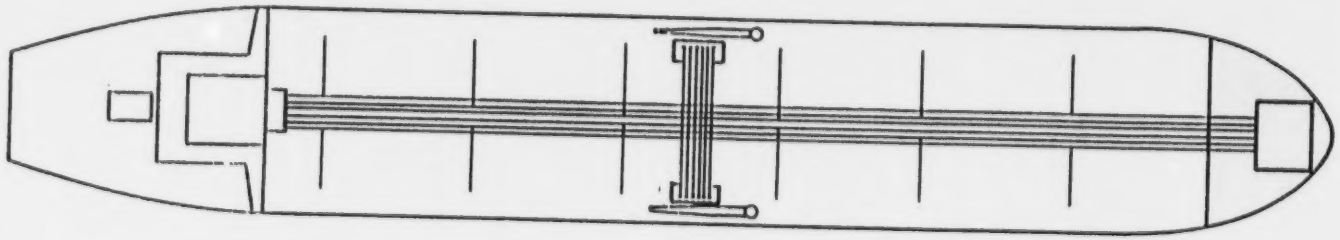
FIGURE 26
- SHUTTLE TANKER -
TYPICAL PROFILE AND DECK PLAN





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7. ANTI-ICING AND DE-ICING METHODS

7.1 General

The environmental conditions conducive to icing by sea spray are:

- air temperatures between -2°C and -29°C
- sea temperatures between 8°C and - 2°C
- wind speeds in excess of Beaufort force 5

Icing from atmospheric sources is caused by:

- freezing rain
- freezing fog
- snow

These conditions are a natural phenomena which occur during the winter months off the Canadian east coast and cannot be avoided by ships which operate in the area.

Ice accretion from sea spray is by far the most common and dangerous in its effect. Atmospheric icing, although additive, is not, by itself, particularly significant, as it rarely causes severe icing.

While no successful means of preventing ice accretion have been established, methods can be used to reduce the amount which can accumulate and to remove ice once it has accreted. These methods are divided into two groups, anti-icing and de-icing.

7.2 Anti-icing Methods

Reduction in the amount of ice which may accrete on a ship can be accomplished by:

- ship design
- ship handling strategy
- thermal methods

7.2.1 Ship Design

Ship design has a major influence on prevention of icing, viz:

- A good bow flare will throw much of the sea spray away from the ship.

- Minimization of handrails, rigging, piping and stays reduces ice accretion possibilities.

- Aero-dynamic design of superstructures and deck components leads to deflection of water particles and results in less water impingement on the surfaces.

- Wheelhouse fronts designed with a forward rake will collect less ice than vertical or backward raked fronts.

Apart from structural considerations which are directed primarily at means to prevent icing which would affect the stability of the ship, prevention of ice accumulation on exposed equipment is also important to ensure its operational efficiency when and if required.

Wherever possible, positioning winches, windlasses and similar equipment within a housing, or under the main deck, with a suitable blanking arrangement for wire and rope openings on the sides of the bow, will provide the necessary protection from sea spray. Where this is not possible, portable covers will prevent ice accumulation from affecting the equipment.

Inflatable liferafts and hydrostatic release mechanisms can be protected from icing by means of appropriate covers, but the positioning of lifeboats requires careful consideration at the design stage of the ship.

7.2.2 Ship Handling Strategy

Ship handling strategy has a significant effect on ice accretion because;

- the speed of the vessel and its heading relative to the wind and waves has a vital influence on the amount of sea spray generated.

- by steaming directly against the wind and waves minimum spray is generated, and the slower the ship's speed, the less frequent is the wave impact, and the amount of spray produced over the ship is reduced considerably.

7.2.3 Thermal Methods

Thermal anti-icing methods which have been applied include;

- electric heating of bridge windows

- electric heat tracing of heli-decks

- electric heat tracing of exposed piping

- thermo-syphon heating

Thermo-syphon heating is a system whereby hot air or a liquid can be used as the working fluid. The principle of the system is illustrated by Figure 27 which shows an open and closed system. In the open system warm air can be supplied from the accommodation or be heated and circulated by a fan. In a closed system a suitable liquid can be used as the circulating medium, since the energy per unit volume is greater than for air or gas.

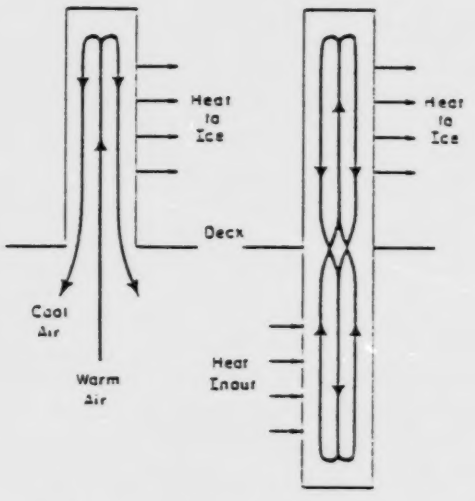


FIGURE 27 OPEN AND CLOSED THERMOSYPHON SYSTEMS

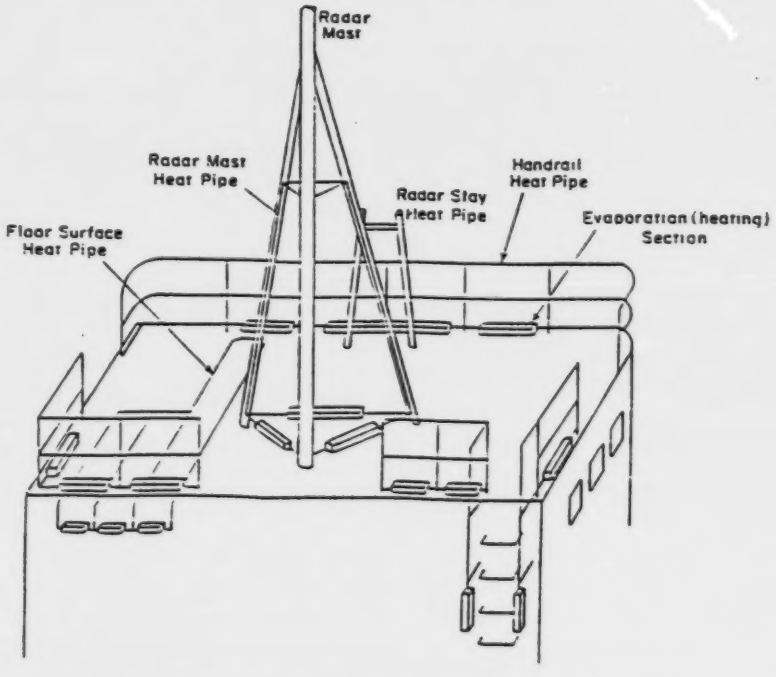


FIGURE 28 PRACTICAL APPLICATION OF THERMOSYPHON SYSTEM

The system is suitable for such exposed components as masts, handrails, and flat areas. Figure 28 is an example of the application of a thermosyphon system which was installed in a new Japanese vessel as a practical means of anti-icing and de-icing (Makonnen 1984). However, such a system would have to be built into a ship at the design stage.

7.3 De-Icing Methods

Various methods of de-icing a vessel have been experimented with both in laboratory and in the field. The methods used include;

- surface coatings
- chemical methods
- thermal methods
- mechanical methods

7.3.1 Surface Coatings

A great deal of research has been devoted to finding a paint coating for external surfaces which would discourage ice adhesion and could be effective for both anti-icing and de-icing. This approach can be advantageous in that painting a vessel is a routine maintenance task, requiring no other special systems or equipment or retrofit.

Laboratory and field tests on coating systems have been carried out by the Norwegian Marine Technology Research Institute (MARINTEK). Various coatings were laboratory tested with respect to mechanical strength, ice adhesion as a function of temperature, and ability to withstand deterioration during several de-icing tests. Table 9 shows an evaluation of the various coating systems tested. Field tests on a ferry partly corroborated laboratory findings that one of the coatings had superior anti-icing and de-icing properties compared to ordinary coatings, as indicated on Table 10. The MARINEK report (Loset 1985) does not specifically identify the coating, but it is believed to be organsol (PVC).

The report indicated that the wheelhouse and parts of the bow had been coated on a standby vessel which was to operate in the hostile waters offshore northern Norway, and that the full scale testing would be undertaken during the 1985-86 winter season.

The Cold Regions Research Laboratory (CRREL) has for some years also pursued research on coatings which would have low ice adhesion properties. A number of newly developed silicon-based compounds are reported to show great promise although field tests have not yet been carried out (Minsk 1984).

Makonnen (1984), while reporting that early experiments with coatings were unsuccessful for anti-icing purposes, states that Russian experiments with coatings of synthetic polymers have proved to be effective in reducing ice adhesion. Full scale tests on a ship showed that polymer coatings, particularly organosilicone epoxy had a decisive effect in reducing ice adhesion.

Coating system	Evaluation of adhesion
Polyester powder (120 microns)	Good adhesion. Rupture in ice for 1 square
Polyester powder (130 microns)	Good adhesion. Rupture in ice for 1 square. The other may be pushed off with heavy hand force
Organosol (PVC)	Very easily removed
Silicone polyester	Better adhesion than Organosol
Kynar PVF	Better adhesion than Organosol
Polyester/Amine	Good adhesion
Epoxy powder (120 microns)	Good adhesion. Rupture in ice for 2 squares
Epoxy powder (130 microns)	Good adhesion. Rupture in ice for 2 squares
Teflon plate	Good adhesion. Rupture in ice
Vinyl system	Good adhesion. Rupture in ice
Vinyl system (as above) with Break-Free Formulae 3	Less adhesion. The squares could be pushed off with hand force
Vinyl system (as above) with Break-Free	Less adhesion. The squares could be pushed off. More force than the above mentioned system
Nylon Rilsan a	Good adhesion. Rupture in ice
Vylastic	Good adhesion. The square could be pushed off by hand

Table 9

Coating System Evaluation

Date	Climate				Ice thickness on test plates	Ice thickness on the plate's adjacent hull
	Wind	Sea spray over bow port	Air temp.	Sea temp.		
26.03	South gentle breeze	No	-12 °C	+4 °C	0 mm	1 mm
27.03	South breeze	No	-7 °C	+4 °C	0 mm	0 mm
28.03	Northeast near gale (snow)	Yes	-8 °C	+3 °C	0 mm	25 mm
29.03	Northeast strong breeze	No	-10 °C	+3 °C	0 mm	30 mm
30.03	Southeast breeze	Yes	-7 °C	+4 °C	0 mm	30 mm
31.03	Southeast strong breeze	Yes	-3 °C	+4 °C	0-10 mm loose ice	25 mm
01.04	Southeast breeze	No	-2 °C	+4 °C	0 mm	0 mm
02.04-16.04			Plus degrees			

Table 10

Coating Field Test Results

Stallabrass (1975) reported that certain polymers and flexible silicone coatings have shown low values in promoting ice release, but with deterioration on subsequent releases. Additional problems of ultraviolet degradation and low abrasion resistance precluded these materials from practical consideration at that time. It is probable, however, that developments since then have improved their de-icing potential.

7.3.2 Chemical Methods

As distinct from permanent paint coatings which are sometimes characterised as a chemical means of anti-icing and de-icing, experiments have been tried of applying freezing point depressants in the form of fluids, at the surfaces to be protected, but with little success. The major problems appear to lie in determining the amount of chemicals required, obtaining uniform distribution over the surfaces, and deterioration of the chemicals. Stallabrass (1975) reported from laboratory experiments that ethylene glycol was effective in reducing the strength and adhesion of ice on flat surfaces, but noted that resultant slippery residues on deck were disadvantageous.

Chemical methods are considered more appropriate for small objects such as bridge windows, automatic meteorological instruments, inflatable liferaft containers, etc (Makonnen; Stallabrass 1980). Chemicals are difficult to apply on large structures for long term anti-icing or de-icing purposes as distribution and rapid deterioration makes the method uncertain.

7.3.3 Thermal Methods

Thermal methods applied for de-icing purposes are identical to those described for anti-icing, as these systems are equally appropriate for the removal of accreted ice. Additionally, however, high pressure jets of sea water are capable of eroding ice cover by virtue of their pressure and temperature. They are especially useful whenever a particularly large ice accretion must be removed quickly.

7.3.4 Mechanical Methods

Mechanical methods or devices for de-icing can be sub-divided into:

- manual
- pneumatic
- vibrations

a) **Manual De-icing** - is carried out by ships crews on deck attacking the ice with mallets, axes and hammers. This can be extremely hazardous and sometimes impossible due to the weather conditions creating the icing.

   Even when conditions allow manual de-icing to be carried out, it is normally not possible for the crew to remove ice from

higher areas which contribute to loss of stability, such as masts and rigging.

b) **Pneumatic Methods** - following the disastrous loss of three British trawlers during the winter of 1967-68, the Palmer Aero Products Company, England developed existing aircraft pneumatic de-icing products for marine use. The pneumatic de-icers consisted of rubber sleeves and overshoes through which air at 15 p.s.i. would be passed in intermittent pulses to break any ice adhering to the surface when the rubber expanded.

The de-icers were fitted to a side trawler, the "Boston Phantom" for practical tests. Figure 30 shows the protected areas which were the fore mast, stays, bridge front, part of the stern and the radar scanner, with the air controls fitted in the wheelhouse.

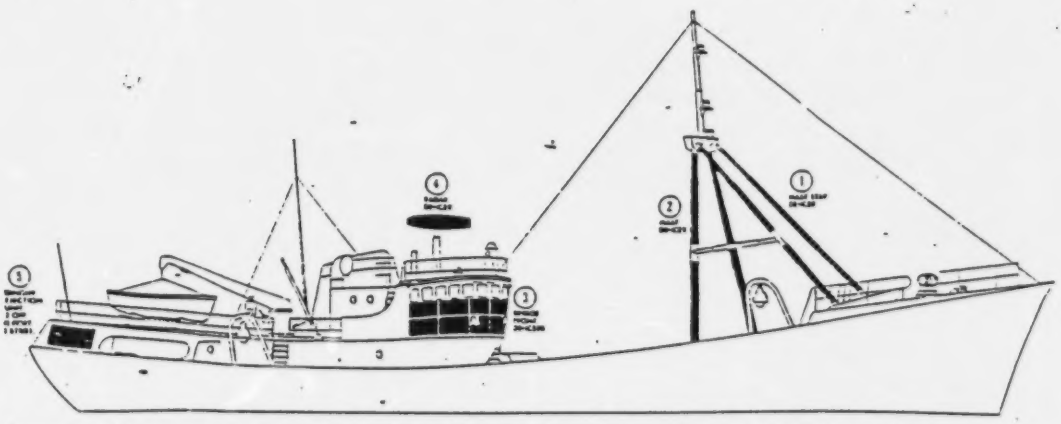
Severe icing conditions were met with an estimated accumulation of ice of 3 tonnes per hour. On inflating the de-icers the ice broke away cleanly. Thicknesses of up to 6" of ice have been cleared without difficulty. No detectable fall off in the performance of the radar was found due to the presence of the de-icers, and in icing conditions, the equipment freed the ice adhering to it, and the picture was notably improved (National Fisherman, 1969; Palmer Products Report 1969; Sea Harvest & Ocean Science January 1970). As the United Kingdom trawlers ceased to fish in arctic waters, the trials were discontinued.

Successful laboratory experiments and outdoor tests with the same type of equipment have been carried out in Canada, and this form of de-icing equipment is considered to hold great promise (Stallabrass 1970). Apart from the de-icing capability of the pneumatic panels, an advantage of the system is that their inflation can be controlled remotely, obviating the need for the ship's crew to go out on deck.

In 1977, the CAPE RODGER, a 61 m Canadian fisheries protection and patrol ship was fitted with pneumatic panels across the superstructure to a height of 3.6 m above the forecastle deck for field test purposes. It was not considered to be cost effective, as the panels deteriorated rapidly, with pin-pricks appearing in the rubber material after a few inflations, causing loss of air. The panels were removed and no further action was taken.

c) **Vibrations** - De-icing tests have been carried out by artifically generated vibrations by means of electro-magnetism. This system is based on de-icing by electro-magnetic shock impulses which generate local mechanical vibrations. The tests have not been successful largely due to the cumbersome nature of the equipment and its unreliability (Loset 1985).

FIGURE 29
BOSTON PHANTOM
PNEUMATIC DE-ICING PANELS



Areas where de-icing equipment is fitted on trawlers. (1) Mast stay de-icer. (2) Mast de-icer. (3) Bridge front de-icers. (4) Radar de-icer. Also shown above at (5) is the proposed location for two easy ejection dinghies or liferafts.

8. RECOMMENDED RESEARCH

8.1 Preamble

Icing will be experienced by vessels operating during the winter months in the Hibernia area off the east coast of Canada. As ship traffic in this area is expected to increase, it will become more urgent to:

a) find the best means of minimising ice accretion.

b) establish the most efficient and cost effective methods of de-icing to maintain equipment in a fully operational condition and provide a safe working environment for ships crews.

Ice accretion can be minimised by effective ship design and by applying methods of anti-icing and de-icing. These are briefly described below:

a) Design

It has been established that a predominant reason for ice accretion is ship generated sea spray. If the amount of spray so generated can be minimised, the extent and severity of icing can be reduced.

Ship design can have considerable influence on both spray generation and ice accretion. On a new ship, appropriate design of forebody with good bow flare and freeboard will do much to reduce the amount of spray which will come on board the vessel and hence reduce icing severity. Reducing obstructions and surfaces on which ice can accrete, and streamlining superstructures to improve air flow will minimise spray impingement and contribute to a reduction in ice accretion.

Other design features which would contribute to the minimisation of ice accretion are:

- clear deck designs with the minimum quantity of above deck equipment to reduce surfaces to which ice may adhere.
- fitting the least number of stays, wires and rails
- fitting forward raking wheelhouse windows

Laboratory tests have been carried out by various researchers to study ice formation and rate of growth on horizontal and vertical surfaces, to assist in determining how design of obstructions or housings could reduce spray impingement or collection. However, tests results are not considered to be of great significance, since their relationship to rates of icing at sea is unknown. No similar tests have been carried out on board ships. Therefore, there is a need to carry out studies at sea to demonstrate the benefits of bow flare and streamline designs of housings, to establish their effectiveness in the reduction of ice accretion.

b) Anti-Icing

Icephobic paints are paints which have been developed with low ice adhesion properties. These paints present a smooth slippery surface which assists in shedding water and reduces the adhesive bond of the ice which has accreted. Hence, ice which does adhere can easily be removed. An advantage of icephobic paints is that they can be applied to existing ships. As these coatings show great promise, extended tests of those available would be advantageous.

Experiments have also been carried out using chemicals with low freezing points to cover the surfaces to be protected. The theory is that they would depress the freezing point of the spray impacting on a surface, and reduce the adhesion of any ice formed. Chemicals used have included glycols and alcohols. This procedure has not been successful for use on large surfaces, and is not considered worth pursuing further.

c) De-Icing

A variety of methods have been used in efforts to remove accreted ice. Traditionally, de-icing has been carried out by crew members, using wooden mallets, crowbars, etc to dislodge the ice. Although successful, and commonly used, it can be a long, tedious and dangerous task. It is quite possible that the use of hitherto untried equipment such as high pressure air or ultrasonics will accomplish the same task in far less time and with little or no danger to personnel. The advantage of these methods is that the ice would not require to be melted, which is an extremely uneconomic process, but would be removed in solid form.

Due to the brittle nature of ice, if the surface on which it has been accreted can be flexed, the ice will crack and be released. This can be achieved on vertical surfaces such as the sides of superstructures by excitation of the natural frequencies of vibration of the panels. Tests using electro-magnets have been tried but were reported as disappointing. This method of de-icing is considered not worth pursuing at present although it may have some potential in the future. Inflatable panels have been used for the same purpose and although Canadian experience has not been good, European tests have shown considerable promise.

Other methods which have been tried include steam hoses and hot water jets. The disadvantage of these methods is that considerable heat is required to melt the ice which may well re-freeze on deck. Thermosyphon systems have a particular application but this method lends itself more to the design of a new vessel. Electric heat tracing of selected components is a proven method of protection for exposed piping and valves and may prove advantageous in specific ship areas although it is costly in terms of energy consumption.

8.2 Recommended Research Programme

In consideration of the foregoing, the following recommendations are made. A detailed test programme is included as Appendix 2.

1. Anti-Icing Systems

a) Icephobic Paints

- Research should be initiated into different types of icephobic paints with a view to determining which, if any, of the paints would be suitable for marine use.

- When suitable paints have been identified they should be tested on board one of the selected ships over a sufficiently long period of time, with adequate controls to be able to assess their effectiveness.

- The tests would not only be with respect to their icephobic properties but also for ease of application, wear resistance and repair of damaged surfaces.

- The coated panels should also be tested for comparison against other panels coated with normal ship's paint.

b) Streamline Designs

- Streamlined and irregular shaped objects should be designed and placed on board ship to test their effectiveness with respect to ice accretion.

- Aerodynamic covers should be designed and fitted to other deck equipment on board the selected ship to test their capability to protect and maintain the equipment in an operational condition.

2. De-Icing Systems

a) Mechanical Systems

- Investigation should be made of manufacturers experienced in the production of inflatable panels and designs drawn up for fitting and testing an appropriate system on board the test ship.

- High pressure air guns similar to those which have been used for boiler cleaning should be researched and a suitable system of compressor and air hoses placed on board for de-icing tests.

b) Thermal Systems

- Electric heat tracing should be installed in suitable locations to testing its capability to maintain safety equipment such as fire hydrants and monitors, in an operable condition, and to measure the power required.

- As ice accretes due to the impingement of supercooled water droplets on to surfaces, if these droplets can be warmed, ice will not form. It is suggested that a water flooding system to maintain flat surfaces wet, may prevent ice formation.

3. Ice Accretion Monitoring

- Investigation should be initiated of suitable instrumentation which can be placed on board to measure ice thickness and rate of ice accretion.

- In conjunction with the ice measurement programme above, research should be initiated into the construction of a model on which typical ship icing patterns can be imposed and the model used to estimate the weight of ice on board, and its effect on stability. The intent would be to develop a simple system to warn a ship's master if ice accretion was approaching a dangerous level.

9. CONCLUSIONS

This work has thoroughly reviewed the literature and present understanding of the problems associated with ship icing on the east coast of Canada. Based on that work a number of conclusions can be drawn.

a) Severe icing can be encountered off the east coast of Canada, and vessels engaged in offshore activities during the months of December to March will experience ice accretion to a greater or lesser extent depending on the severity of the weather.

b) Ship icing may be caused by sea spray or arise from atmospheric sources or be a combination of both. Sea spray is the most frequent and severe cause of ice accretion, although spray icing in combination with wet snow has been a common occurrence. Typical east coast icing duration is 15 hours with ice accretion thicknesses averaging 5 to 6 cms during this period.

c) The Hibernia offshore region lies well within the area of icing potential which extends from about latitude 40°N to 60°N and for a distance of about 200 miles off the coast.

d) International icing literature is quite extensive, but is lacking in quantitive data with respect to the vertical distribution of sea spray, observed superstructure icing, weight of accreted ice and how it has affected stability.

e) There is a considerable number of ship icing reports held by the Canadian Coast Guard, mainly from fishing vessels. Because of their construction, the nature of their activities and location of the fishing grounds, the reports are not necessarily indicative of icing events that may affect offshore ships operating in the Hibernia area. However, there are sufficient reports from offshore vessels to indicate that severe icing can be experienced in vessel transits to and from Hibernia and the mainland.

f) Ice accretion on vessels reduces their stability and in extreme cases can cause ships to capsize. All exposed equipment on deck and in particular lifesaving and firefighting equipment can be made inoperable and personnel safety put at risk.

g) The allowable ice load stipulated in the appropriate regulations made under the Canada Shipping Act provides an adequate safety margin with respect to stability, for vessels projected to operate in the Hibernia area.

h) Ice accretion on ships cannot be prevented but measures can be taken to reduce the amount of ice accreted. Very little work is reported in the literature on efficient and cost effective methods to retard ice accretion and to de-ice a vessel once ice has accreted. There are reports however of methods used experimentally with varying degress of success.

These conclusions, supported by the proposed research programme represent from a mariners viewpoint the present understanding of this difficult and persistent problem. By pursuing the research programme it should be possible to develop some practical solutions for ships which must spend substantial time in the Hibernia area.

BIBLIOGRAPHY

Agnew, T.A.; Swail V.R.
Proceedings international workshop on offshore winds and icing. Environment Canada, Atmospheric Environment Service, Downsview, Ontario, 407 pages. 1985

Appleby, J.R.
Icing and associated problems in Canada. Det Norske Veritas Report No. 83-8525, 40 pages. 1983

Bardarson, H.R.
Icing of ships. In proceedings of the Second International Conference on Port and Ocean Engineering under Icing Conditions, pp. 185-202. 1973

Beal, R.; Johnstone, K.; Gigliotti, T.; Jandali, T.
Observation of sea spray icing and outflow wind at Green Island, British Columbia. Proceedings, International Workshop on Offshore Winds and Icing, Halifax, N.S. 1985

Borisenkov, E.P.
Investigation of the physical nature of ship icing. CREEL, September 1984

Borisenkov, Ye P.; Pchelko, I.G.
Indicators for forecasting ship icing. Report No. CRREL-TL-481.54 1975

Brown, R.D.; Agnew T.
Characteristics of marine icing in Canadian waters. Proceedings, International Workshop on Offshore Winds and Icing, Halifax, N.S. 1985

Brown, R.D.; Agnew, T.
Evaluation of currently available marine icing models for prediction of icing on ships and offshore structures. Proceedings, International Workshop on Offshore Winds and Icing, Halifax, N.S. 1985

Brown, R.D.; Roebber, P.
The ice accretion problem in Canadian waters related to offshore energy and transportation. Canadian Climate Centre, Report No. 85-13 (unpublished manuscript), 295 pages. 1985

Buianov, N.F.
How to fight icing of ships. UDK 639.2.05, pp. 30-32. 1967

Buianov, N.F.; Kokaev, V.A.; Naumov, G.K.
Observing ship icing near the ice-edge zone of the Bering Sea in 1971-72 (in Russian), pp. 144-151. 1971

Cacam, D.J.
Ice accretion on ships. U.K. Ministry of Defence, Navy Dept.

Carlson, R.F.; Zarling, J.P.; Hok, C.I.
Engineering for vessel ice accretion with particular reference to the Alaskan fishing fleet.

Corben, F.
De-icing methods and engine noise reduction. Naval Scientific and Technical Information Centre, Ministry of Defence, Navy Dept., U.K. 1970

Dacam, D.
Ice accretion in ships. Naval Scientific and Technical Information Centre, Ministry of Defence, Navy Dept., U.K. 1970

Feit, D.M.
Ship superstructure ice accretion guidance forecasts. Proceedings, International Workshop on Offshore Winds and Icing, Halifax, N.S. 1985

Globe & Mail
Icing danger poses threat to seaway. 1975

Hay, R.F.M.
Meteorological aspects of the loss of Lorella and Roderigo. The Marine Observer, April 1956

Horjen, I.
Icing of structures. Marine structures and ships in ice. The Association of Chartered Engineers in Norway, Oslo, Mar. 9-10, 1982. Paper No. 3.29 1982

Horjen, I.; Vefsnmo, S.
A numerical spray icing model including the effect of a moving water film. Proceedings, International Workshop on Offshore Winds and Icing, Halifax, N.S. 1985

Houmb, O.G.; Strass, P.
Sea spray icing and mesocsale meteorology in relation to marine technology. Proceedings, International Workshop on Offshore Winds and Icing, Halifax, N.S. 1985

Itagaki, K.
Ice rate on stationary structures under marine conditions. CREEL 1984

Jorgensen, T.S.
Ice formation on fishing vessels. Skipsnytt, 22 pages. 1982

Jorgensen, T.S.
Icing of fishing vessels. Skipsmtt 1982

Jorgensen, Tore S.
Influence of ice accretion on activity in the northern part of the Norwegian continental shelf. Report No. STF88 F82016, 121 pages. 1982

Kilgour, R.; Brown, W.K.
Degradation of communication on AWF ship antennas in an icing environment at sea. N74-14909 (on microfishe), 65 pages

Kolosova, N.V.; Panov, V.V.
Meteorological conditions for icing of above-water objects in the shelf zone of arctic seas, pp. 100-109. 1981

Kuznetsov, V.P.
Effect of icing on the stability of ship. Theoretical and experimental studies of ship icing, pp. 77-86. 1971

Liljestrom, G.
Icing on semi-submersible platforms. Proceedings, International Workshop on Offshore Winds and Icing, Halifax, N.S. 1985

List, R.
Ice accretion on structures.

Lock, G.S.H.
Some aspects of ice formation with special reference to the marine environment, pp. 175-184. 1972

Lonsdale, Joseph T.; Norrby, Tomas
Electric heat tracing designed to prevent icing. Drilling, Chapter 3, pp.25-29

Loset, Sveinung
Investigation and Research on Anti-icing and de-icing devices for marine application. Norwegian Marine Technology Research Institute

Loset, Sveinung
Winter drilling off Norway. Maritime Offshore, pp. 12-14. 1985

Lowsowski, E.; Gates, E.
Marine icing models: How do they work and how good are they?. Proceedings, International Workshop on Offshore Winds and Icing, Halifax, N.S. 1985

Lozowski, E.P.; Gates, E.M.
An overview of marine icing research. 4th International Offshore Mechanics and Arctic Engineering Workshop, ASME 1985

Lundguist, J.E.; Udin, I.
Ice accretion on ships with special emphasis on Baltic conditions. Helsinki, Finland: Winter Navigation Research Board. Research report no. 23, 32 pages. 1977

MacDonald, K.A.; Jessup, R.G.
Evaluation of a freezing spray forecast system. Proceedings, International Workshop on Offshore Winds and Icing, Halifax, N.S. 1985

Makkonen, L.
Icing rates on cylindrical structures. Proceedings, International Workshop on Offshore Winds and Icing, Halifax, N.S. 1985

Makkonen, Lasse
Atmospheric icing on sea structures. pp. 1-93 1984

Martec Ltd.
Evaluation of emergency equipment and sea rescue techniques for use from mobile offshore drilling units in Canadian waters. COGLA 1983

Matthews, P.
British made de-icing gear is effective safety feature. National Fisherman, pp. 29A 1969

Maxwell, J.B.; Duck, P.J.; Thomson, R.B.; Vickers, G.C.
The climate of northwestern Baffin Bay. Atmospheric Environment Service, Downsview, Ontario 1980

McKay, G.A.; Thompson, H.A.
Estimating the hazard of ice accretion in Canada from climatological data.

McLeod, W.R.
Atmospheric superstructure ice accumulation measurements. P.O.A.C. 1981

Mertins, H.
Icing of fishing vessels due to spray.

Meteorological & Environmental Planning Ltd.
Climatology of the east coast marine areas. Atmospheric Environmental Service (unpublished report), 142 pages. 1984

Ministry of Defence, Navy Dept., United Kingdom
Seminar on Trawler safety. Operations and maintenance of deep-sea trawlers under arctic conditions. A seminar held at the Admiralty Surface Weapons Establishment and the Admiralty Experiment works on June 23/70, Orpington, England, pp. 72. 1970

Minsk, L.D.
Assessment of ice accretion on offshore structures. Cold Regions Research and Engineering Laboratory, Hanover, NH 03755, pp. 247-257. 1984

Minsk, L.D.
Measurement of icing on offshore structures. Proceedings, International Workshop on Offshore Winds and Icing, Halifax, N.S. 1985

Mitten, P.; Paschke, P.; Brown, R.D.
Atmospheric icing on oil rigs off Canada's east coast. Proceedings, International Workshop on Offshore Winds and Icing, Halifax, N.S. 1985

Morimura, Shinji
Studies on the ice accumulation on ships. III. on the prevention of icing on ships by membranous water. Hokkaido Daigahu Suisangakubu Kenkyo Ibo, pp. 29-38 1972

Mortsch, L.D.; Agnew, T.; A. Saulesleja; Swail, V.R.
Marine Climatological atlas - Canadian east coast. Canadian Climate Centre, Report No. 85-11 (unpublished report, 343 pages. 1985

Nauman, J.W.; Tyasi, R.
Superstructure icing and freezing conditions of offshore drill rigs, Alaska experience and regulatory implications. Proceedings, International Workshop on Offshore Winds and Icing, Halifax, N.S. 1985

New Scientist
Icing of ships - a Soviet view, pp. 404-405. 1978

Ocean Engineering
Arctic offshore problems examined, pp. 14-18. 1970

Offshore
Polar frontiers challenge oil explorers. Polartech, Helsinki 1986

Okihara, T.; Kanamori, M.
Design, testing and shipboard evaluation of a heat pipe de-icing system. Thermophysics Conference, Colorado, July 1980

Ono
Studies of ice accumulation on ships, Part II, conditions of icing and accreted ice weights. Low Temperautre Science (Teion Kagaku), Series A, 14 pages. 1964

Overland, J.E.; Pease, C.R.; Dreifsendorfer, C. et al
An algorithm for prediction of vessel icing. Proceedings, International Workshop on Offshore Winds and Icing, Halifax, N.S. 1985

Palmer Aero Products
De-icing apparatus for ships.

Paniushkin, A.V. et al
Results of field tests of anti-icing methods (In Russian). 1972

Panov, V.V.
Icing of ships. Polar Geography, pp. 166-186. 1978

Parfenov, A.F., Balanin, V.V.; Ivanov, L.V.
Effect of ice on ships and structures and maintenance of their operation at sub-zero air temperatures. Brussels, Belgium: Permanent International Assoc. of Navigation Congresses, pp. 165-200. 1973

Parsons, R.C.; Hopkins, R.M.
A chemical method for ice destruction. POAC 1977

Petherick, V.C.
Icing on radar and communication aerials. Naval Scientific and Technical Information Centre, Ministry of Defence, Navy Dept., U.K. 1970

Petroleum Engineer
Arctic offshore problems examined. 1970

Plakhotnik, A.
Icing of ships and vessels (In Russian). Source: COLD, pp. 73-78. 1982.

Polar Record 15 (96)
De-icing apparatus for ships. pp. 343-344. 1970

Rozentsveig, V.B.
Effect of icing on seaworthiness and stability of fishing boats (In Russian). Theoretical and experimental studies of ship icing, pp. 70-76. 1971

Rybnikov, B.N.
Analysis of a unique case of icing of the medium fishing trawler "Piarnu" (In Russian), pp. 132-140. 1975

Sea Harvest and Ocean Science
De-icing equipment for trawlers. Sea Harvest & Ocean Science pp. 23-25, 1969-70.

Shekhtman, A.N.
Hydrometeorological conditions in the icing-up of vessels at sea. Naval Scientific and Technical Information Centre, 20 pages 1984.

Shekhtman, A.N.
The probability and intensity of the icing-up of ocean-going vessels. Report No. NSTIC-Trans-2312; NSTIC-29795 1971

Shellard, H.C.
The meteorological aspects of ice accretion on ships. World Meteorological Organization, Geneva, Switzerland, 34 pages. 1974

Stallabrass, J.R.
Icing of fishing vessels in Canadian waters. Low Temperature Laboratory, Division of Mechanical Engineering, pp. 25-43. 1975

Stallabrass, J.R.
Icing of fishing vessels: An analysis of reports from Canadian East Coast waters. National Research Council Canada. Division of Mechanical Engineering Report June 1979-LTR-LT-98, 23 pages. 1979

Stallabrass, J.R.
Methods for the alleviation of ship icing. Mechanical Engineering Report, MD-51, NRC No. 11872, 130 pages. 1970

Stallabrass, J.R.
Trawler Icing: A compilation of work done at N.R.C. Mechanical Engineering Report, MD-56, NRC No. 19372, 103 pages. 1980

Swail, V.R.; Mortsch, L.D.
A review of the state-of-the-art in marine climatology on the east coast of Canada. Environment Canada, Atmospheric Environment Service, Downsview, Ontario 1984

Tabata, T.
Research on prevention of ship icing. Defence research board, pp. 1-18. 1968

Thomson, G.
Icing and de-icing of distant water trawlers. Naval Scientific and Technical Information Centre, Ministry of Defence, Navy Dept., U.K. 1970

Thomson, G.
Icing and de-icing of distant water trawlers model testing. U.K. Ministry of Defence, Navy Dept.

Vasil'yeva
Hydrometeorological conditions causing ice accretion on ships. 1966

Verevkin, V.F.
Selecting a propulsion means for icebreakers and ice navigation ships in the far eastern basin (In Russian), pp. 184-185. 1976

Ward, H.L.
The icing and de-icing of marine radar aerials. Naval Scientific and Technical Information Centre, Ministry of Defence, Navy Dept., U.K. 1970

Wise, J.L.; Comiskey, A.L.
Superstructure icing in alaskan waters. Pacific Marine Environmental Laboratory, Seattle, Washington, 30 pages. 1980

Wu, J.
Sea spray: a further look. Journal of Physical Research, October 1982

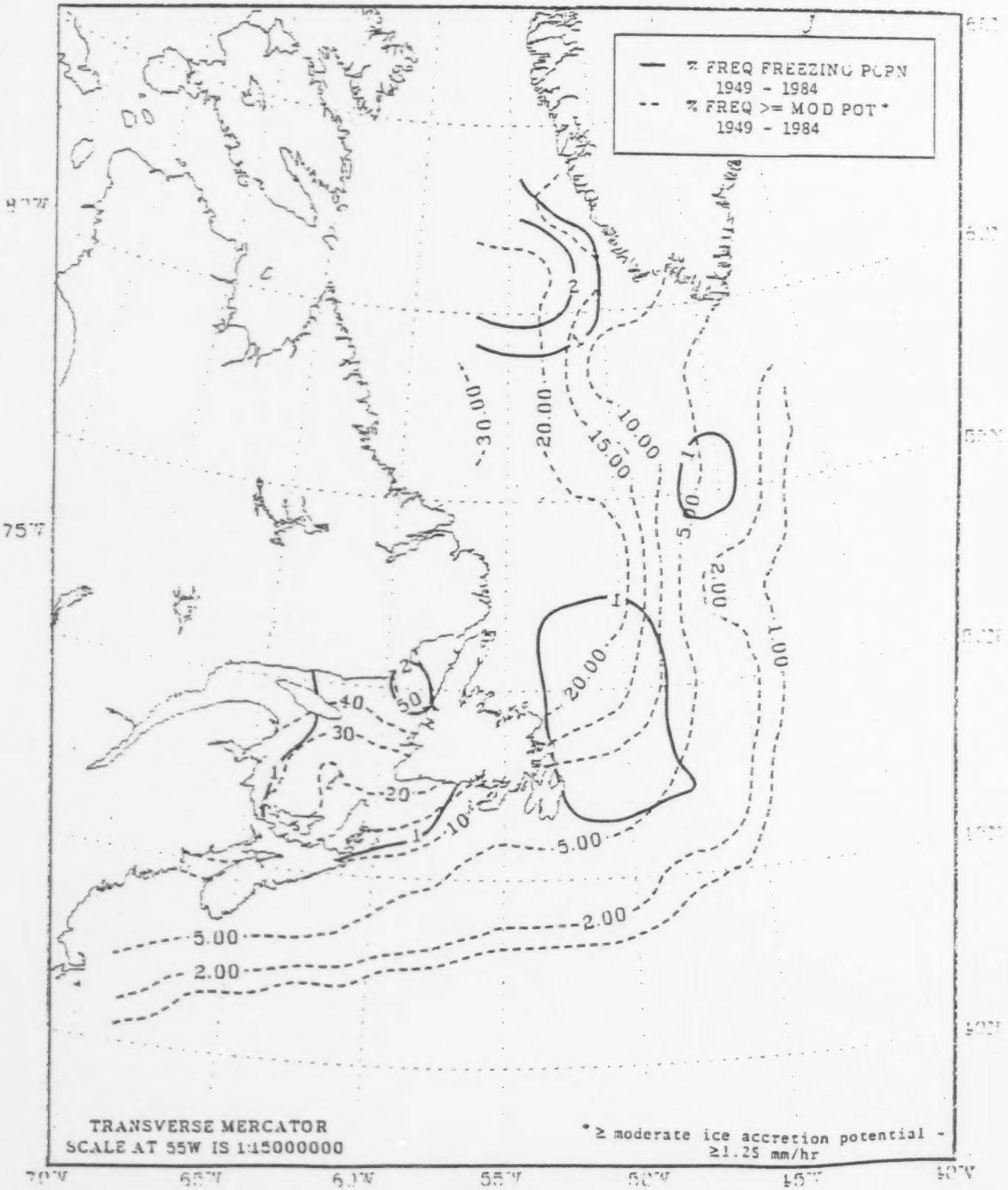
Wu, J.; Murray, J.J.; Lai, R.I.
Production & distribution of sea spray.

Yerokhin, Ye.
Safety of shipping under icing conditions. Odessa Polytechnic Institute, pp. 106. 1968

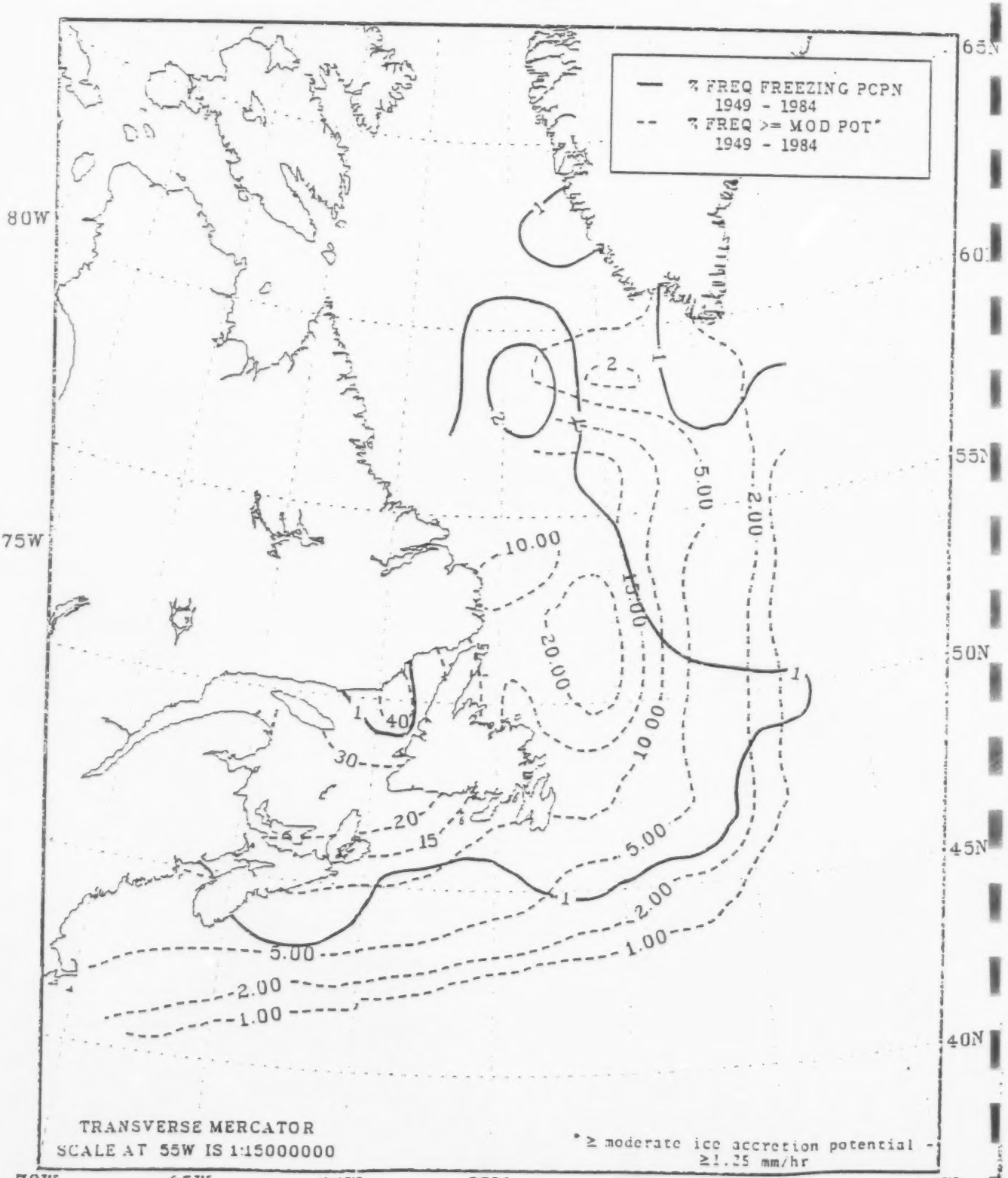
APPENDIX 1

ICE ACCRETION CONTOUR MAPS

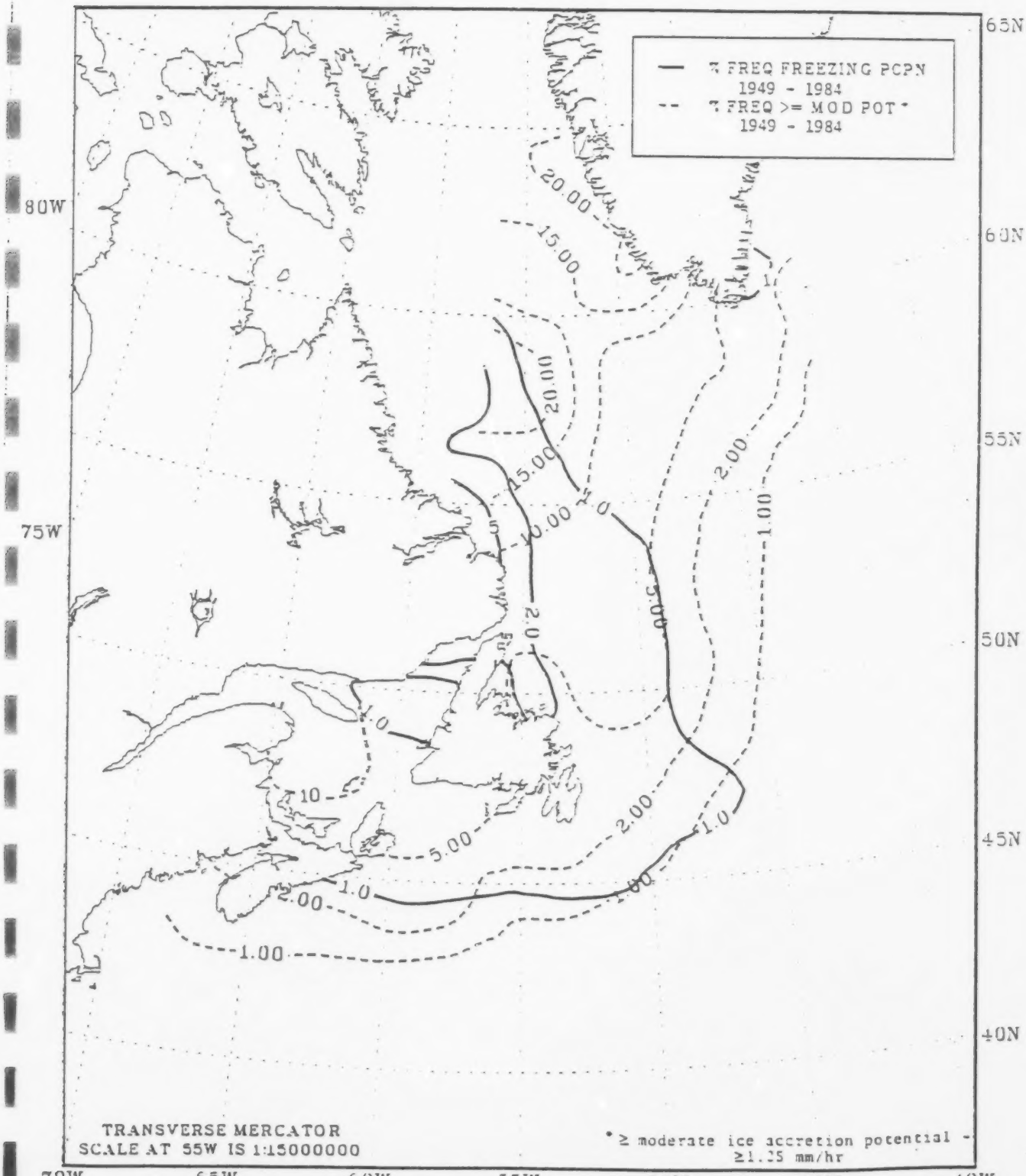
ICE ACCRETION
JANUARY



ICE ACCRETION
FEBRUARY



ICE ACCRETION
MARCH



APPENDIX 2

RECOMMENDED TEST PROGRAMME

A2. RECOMMENDED TEST PROGRAMME

Project #1:

To evaluate the usefulness of a water curtain or cascade system in the prevention of ice build up on the front of superstructures.

Project Background:

Ice accretion on ships is principally due to supercooled water droplets striking the vertical surfaces and being converted to ice on impact. If the supercooled water droplets are warmed at impact by, say a water curtain, freezing would not take place. Either the engine cooling water could be used as a source of warm water or the sea water could be used if it was above the freezing point of water.

Work Statement:

Phase I - Laboratory Tests

1. The physics of ice accretion on ships will be investigated and the quantity and temperature of water required for a water curtain on a ship will be determined. By study of the cooling system of the main or auxiliary engines on board ship, it will be determined if sufficient water at the required temperature is available from this source.

2. A laboratory experiment will be designed to demonstrate if it is feasible for a water curtain system to maintain a superstructure of a ship in a de-iced condition. Typical icing conditions as found off the east coast of Canada will be simulated during the test.

3. A report of the experiment will be submitted which will clearly identify all work carried out, the results of the experiment and make recommendations as to whether full scale tests should take place.

Cost Estimate and Time Required to Complete:

Total Cost $50,000

Time to Complete: 4 months

Phase II - Field Tests

1. From the work carried out under Phase I, a full scale experiment on board a typical OSV operating off the east coast of Canada will be carried out to demonstrate the usefulness of a water curtain to inhibit icing on a superstructure.

2. A system of pipes will be arranged through which a fine spray of water will be directed to impinge on the front of a superstructure. This piping system may be supplied with either seawater or water from the engine cooling system.

3. The system will be tested under icing conditions and observation made of icing events if any.

4. The system shall be arranged such that the water flow rate can be adjusted and the flow rate measured. Experiments will be made to determine the most economic flow rate to prevent ice from forming.

5. Each time the system is used, accurate records of the environmental conditions will be made to include seawater and air temperature, wind speed, ships speed and heading, and sea state.

6. At the conclusion of the first year of operation a report will be compiled describing the system, the experiments which were carried out and the results. If the results indicate the system is useful in preventing ice from forming, the experiment will be extended by another year.

7. At the completion of the tests all work will be described in a report, including costs to purchase the parts and fit the system. The flow rates used for the water curtain will be described and conclusions drawn as to the relationship between flow rates and environmental conditions.

Cost Estimate and Time Required to Complete:

First Year Cost	$50,000
Second Year Cost	$30,000
Total	$80,000

Time to Complete: 1.5 Years (two icing seasons)

Project #2:

To assess the affects of streamline shapes, surface finish and ice phobic paints on the rate of ice accretion on the superstructure of typical ships.

Project Background:

Published literature has suggested that by the use of streamlined shapes the quantity of supercooled water droplets impinging a surface can be reduced and hence the rate of ice accreted can also be reduced. Reports also indicate that certain paints inhibit the formation of ice or reduce its adherence.

The influence of shape and surface finishes on the rate and quantity of ice accreted on a surface can be assessed either by field tests on ships or by laboratory experiments in a cold room. Both approaches have their particular advantages and disadvantages.

Experiments in a cold room have the distinct advantage of being able to precisely define and control the environment, will permit the experiment to be repeated, and allows reliable measurements to be made which can be rigorously analysed.

Experiments on board ship can only be made on an opportunity basis, as it is difficult to predict when icing will occur and to make the precise measurements to describe the environmental conditions at the time. The experiments are non-repeatable as conditions are never completely identical from one time to another, therefore, comparisons are difficult to make. Conclusions made from field tests tend to be subjective and are therefore open to debate. Field tests do have the very real advantage of true-to-life circumstances and the compilation of full scale data.

Statement of Work:

Phase 1 - Laboratory Tests in Cold Chamber

1. One or more streamline shapes will be designed to represent the shape of an aero-dynamically designed superstructure for a ship. In addition, shapes will be designed with good aero-dynamic properties which could be used to shelter exposed equipment on a ship, e.g. lifeboats in their davits, winches, etc. The shapes designed should be practical. The scale of the shapes will be consistent with the size of the cold chamber.

2. A non aero-dynamic shape will be designed to typify a poorly designed superstructure. This shape will be to the same scale as the shape in 1, and this shape will be used as a control.

3. The streamline efficiency between the two shapes will be measured and a drag coefficient determined, if appropriate.

4. Each shape will be tested in a cold room with its control under icing conditions. Various tests will be carried out using at least three wind speeds, from light airs to Beaufort 10 and at least three wind directions from dead ahead, 45° to the bow and athwartships. For each test the rate of ice accretion will be measured and ice maps drawn to permit the influence of shape to be assessed. The shapes will be finished with a standard marine paint finish.

5. The shapes will be recoated using at least two icephobic paint systems which literature and previous work has indicated are the most promising. Ice accretion tests will be repeated under identical conditions to the worst icing conditions measured from Task 4. At the completion of the tests, measurements will be made to determine the ice distribution over each shape and the strength of the ice bond to the painted surfaces.

6. A comprehensive report will be prepared to describe all work carried out and the results of all experiments with conclusions and recommendations. The cost of ice phobic paint systems will be stated and an assessment of their durability as compared to conventional systems discussed.

Cost Estimate and Time to Complete:

Total Cost - $100,000

Time to Complete: 8 months

Phase II - Field Tests

To design and carry out tests on board a typical OSV operating off the east coast of Canada, in areas in which severe icing is known to occur, to determine the influence of streamlines and surface finish on the rate of ice accretion on surfaces of ships.

1. One or more streamline shapes will be designed to represent a ships superstructure and cover(s) for equipment exposed on deck. These shapes will be as large as possible for mounting on the forepart of a ship.

2. A plate type structure with the minimum of aero-dynamic properties will be constructed as a control.

3. Both shapes will be painted with at least three paint systems in such a manner that comparisons can be made of the effectiveness of each paint system in inhibiting ice accretion.

4. An agreement will be made with a shipowner for these painted structures to be mounted on board a ship for a test period of not less than two icing seasons. It will also be agreed that the ships officers will keep accurate records of icing of each structure according to a documented test schedule.

5. Measurements will be made of each icing condition by recording sea and air temperature, wind speed, relative direction of wind, ship's heading and speed, ships position. Measurements will be made as accurately as possible and at sufficient intervals to calculate rate of ice accretion.

6. A comprehensive report will be prepared at the end of each operating season as will a final report in which the experiments will be described. Icing maps for each structure will be drawn for each incident. Conclusions with respect to the effectiveness of shape in reducing ice build-up and the use of icephobic paints will be assessed. The durability of the icephobic paints and their cost in comparison with conventional paint systems will be reported.

Cost Estimate and Time to Complete:

It is proposed that this work is carried out on an opportunity basis when the ship is operating normally. It would not seem to be practical to charter a vessel to attempt to carry out this work.

First Year Cost	$ 60,000
Second Year Cost	$ 50,000
Total	$110,000

Time to Complete: 1.5 Years (two icing seasons)

Project #3:

To investigate and evaluate by trials on board ships the use of pneumatic air hammer boiler cleaning tools for removal of ice.

Project Background:

Ice accumulations on ships is traditionally removed manually by breaking the ice using wooden mallets. This is a labour intensive operation, may cause damage to equipment and injuries to seamen using the mallets.

There are available a variety of pneumatic hammers designed for use in cleaning hard deposits from boilers. These tools use pulsating blasts of high pressure air to apply hammer like blows to the surface and break the hard deposits. These devices may be useful in breaking ice from surfaces without running the risk of causing damage and with greater efficiency. Most ships are equipped with high pressure air supplies for engine starting air services and therefore the system could be experimented with economically.

Statement of Work:

1. The number of suitable air driven tools which are available which could be used to break ice from ships superstructures and equipment will be researched and costed.

2. The tools which display the largest potential for use to remove ice will be purchased and tested on board one or more ships. The usefulness of the tools will be determined from observations of the operators and compared with the more traditional methods presently used.

3. A report on the tools tested and the efficiency of the tools, ease of application of the tools and the operators opinions will be documented.

Cost Estimate and Time Required to Complete:

Total Cost $ 30,000

Time to Complete: 5 months

Cost Estimate and Time Required to Complete:

Total Cost $35,000

Time to Complete: 3 months

Phase II - Field Tests

Based on the assumption that the findings of Phase I recommend the worth of inflatable panels, Phase II of the project should be implemented.

To carry out tests to demonstrate the usefulness of inflatable panels as de-icing devices on board a OSV.

1. From the findings of Phase I, one or more manufacturers will be consulted with the view to the construction of one or more inflatable de-icing panels to be fitted on board a typical Canadian OSV operating off the eastern seaboard of Canada. Costs of the panel will be determined, deliverability and the selection of materials and air system made.

2. A Canadian operator or owner of an OSV will be approached with the view to permitting one or more inflatable panels to be fitted to his vessel for evaluation purposes.

3. The inflation system of the panel(s) will be designed in conjunction with the manufacturer of the panel, and taking recognition of previous experience, manufactured and fitted to the test ship.

4. The panel will be tested in service for its effectiveness and the ship owner or operator will ensure the co-operation of the ship's crew to accurately document experiences of the use of the panel. A comprehensive log sheet will be drawn-up in order that all important parameters are recorded.

5. The test period will be for at least two icing seasons, i.e. over two years. At the end of the first year an interim report will be issued covering the design installation and experience of the first year of operation. At the end of the second year a final report will be issued which will incorporate the interim report and the second year of operation. The final report will contain an assessment of the usefulness of the panel as a de-icing device, costs to purchase and install for a typical vessel, and operating and maintenance costs of the system. Opinions of the ship's crew and managers will be included in the report of the performance of the system.

Project #4:

To investigate present day experience and the effectiveness of the use of inflatable panels for de-icing ships.

Project Background:

Inflatable panels have been experimented with in both Canada and the United Kingdom as a means to prevent build up of ice on trawlers. The Canadian experience indicated that there were problems of durability of the panels as they quickly became holed.

In the United Kingdom good results were reported without problems of durability. Unfortunately, due to the reduction of interest by the United Kingdom fishing fleet in operations in arctic waters, where icing occurred, their experiments were discontinued.

Since the time of these experiments, there have been developments of materials and more knowledge gained on the subject of icing. As icing is a severe problem for small ships, these experiments should be continued as they are the only tests of anti-icing equipment which are favourably reported.

Statement of Work:

Phase I

1. A search of previously published work on the use of inflatable panels will be made and the results of the experiments noted.

2. Owners, manufacturers and designers of inflatable panels will be consulted to investigate their experience with the use and manufacture of the panels. The use of more recently developed materials for the panels will be discussed.

3. An assessment of the suitability of the use of inflatable panels for OSV's will be made to include the cost of the panels, their durability, method of installation, operation of the system and cost.

4. A test programme to be mounted on board a typical ship will be designed to evaluate the use of inflatable panels as a de-icing device on board ship.

5. A report will be presented of the results of the investigations with conclusions and recommendations.

Cost Estimate and Time Required to Complete:

First Year Costs	$ 75,000
Second Year Costs	$ 40,000
Total	$115,000

Time to Complete: 1.5 Years (two icing seasons)

Project #5:

To evaluate the usefulness of trace heating in maintaining ice free valves, fire hydrants, deck fire monitors and other items of minor, but essential, exposed deck equipment.

Project Background:

Icing on board ships can render useless essential valves and equipment on deck. Fire hydrant valves can become ice covered and inoperable, foam monitors can become seized, pipework which cannot be drained or routed below decks can freeze. One method to prevent this is by heat tracing this equipment.

Heat tracing may take the form of wrapping the parts to be heated with a high resistance electric cable and applying a low voltage. The heating element and the part to be heated will be insulated against heat loss and to minimise the energy required. This system can be used for cargo ships and other ships which do not carry hazardous or inflammable substances.

Where a danger of fire exists, heat tracing using either steam or a 'thermal fluid' can be used. These systems require the parts to be heated to be traced with small diameter pipes through which is passed either steam or a heated fluid with a high specific heat, usually a special oil. As with the case of electrical heat tracing, fluid heat tracing also requires the tracing pipework and the heated parts to be well insulated.

Statement of Work:

1. A literature search of the various forms of heat tracing will be carried out with special reference to the cost of initial installation, operation and maintenance of each system.

2. Designers with experience of heat tracing system will be consulted to determine the usefulness of heat tracing systems to maintain valves, foam monitors and other items of exposed deck systems ice free.

3. A heat tracing system will be designed for a typical Canadian OSV to maintain de-iced fire hydrant valves and other valves and systems which must be maintained operational at all times and would be suitable to heat trace.

   Two systems will be designed:

   a) based upon a low voltage electrical system

   b) based upon the use of a terminal fluid and either a direct fired, indirect heated (using waste heat from the engines) or an electrical heat exchanger.

Both systems will be costed with respect to capital, installation, maintenance and operating costs.

3. An agreement will be made with a Canadian shipowner to fit the system(s) to his ships, one electrical system and a fluid based system on a sister ship.

4. A test programme will be designed to permit the performance of the two systems to maintain the equipment in an ice free condition.

5. At the conclusion of the test programme which is anticipated to be based upon two years, a report will be submitted describing the experiment the costs of each system and the comparative performance.

   The report will make recommendations which system is the better and other recommendations as to how the systems could be improved.

Cost Estimate and Time Required to Complete:

First Year Costs	$105,000
Second Year Costs	$ 20,000
Total	$125,000

Time to Complete: 1.5 Years (two icing seasons)

Project #6:

To develop a simple computer based instrumentation system to measure the weight of accreted ice on a ships structure and calculate its influence on the ships stability. The intent of the instrument is to provide a warning to a ship's Master of impending danger to stability due to icing.

Project Background:

Icing of ships introduces two problems, the major of which is a reduction in stability of the vessel which may lead it to capsize. The secondary problem is a loss of use of ships deck equipment and the introduction of hazardous working conditions.

Many small vessels have been lost due to icing. These losses are not due to the ignorance of the Masters of ships of the danger of icing leading to loss of stability, but of lack of judgement of the affect of icing on their vessels. On small ships, such as fishing vessels, the margin between adequate reserve stability and a hazardous situation can change very quickly as topside weight increases.

Statement of Work:

1. Instrument designers and manufacturers will be consulted to determine the availability of an efficient and inexpensive device which will permit ice thickness to be easily measured electrically. The device may be based upon change of electrical resistance, such as a strain gauge or thermocouple type of instrument; an instrument based upon ultrasonics or upon the vibratory response of panels.

2. By use of the instrument(s) from 1, software will be developed to convert ice thickness measurements to weight distribution and the weight distribution to stability information. It is anticipated that the ice thickness measurement instruments will be arranged in a coarse grid over the area to be protected.

3. The system will be demonstrated in a laboratory under simulated conditions to show it will provide the required stability information and have appropriate alarm functions if preset limits are exceeded.

4. The system will fail safe, that is a malfunction in the system shall not provide erroneous information which could jeopardise the ship. In this regard auto check facilities should preferably be incorporated into the system and auto-calibration system for the ice thickness sensors.

5. The cost of the system to be fitted to a typical OSV will be determined using commercially available equipment.

6. At the completion of the work a report will be prepared which thoroughly describes the operating principles, the software which has been developed, and the specification of all the hardware. Where appropriate circuit and block diagrams of the equipment will be provided.

Cost Estimate and Time Required to Complete:

Total Cost $65,000

Time to Complete: 5 months

APPENDIX 3

LITERATURE SOURCE SUMMARY SHEETS

TITLE: Icing of Ships

AUTHOR: H.R. Bardarson

SOURCE: (See Bibliography)

ABSTRACT:

The paper discusses the reason for ice accretion on ships with particular reference to fishing vessels. It reports on the icing predictions made by the Icelandic Meteorological office and how they compare with icing experienced by fishing vessels.

The effect of icing on ship stability is considered and methods whereby the danger of icing can be reduced are presented.

TITLE: The Ice Accretion Problem in Canadian Waters Related to Offshore Energy and Transportation.

AUTHOR: Brown R.D. & Roebber P.

SOURCE: Atmospheric Environment Service 1985 (unpublished Manuscript)

ABSTRACT:

The objectives of the study were to:

(1) Delineate the scope of the icing problem in Canadian waters identifying offshore industry needs for icing-related information

(2) Compile and analyse a database of vessel icing information from Canadian waters.

The report includes a general discussion on icing of offshore structures and aircraft, a discussion of the characteristics of icing in Canadian waters.

Problem areas in the modelling of ice accretion on ships and structures are identified and anti- and de-icing strategies discussed. The results of consultations with the offshore oil industry and regulatory bodies are also included.

TITLE: A Numerical Sea Spray Icing Model Including the Effect of a Moving Water Film

AUTHOR: I. Horjen & S. Vefsnmo

SOURCE: International Workshop on Offshore Winds and Icing, Halifax 1985

ABSTRACT:

A theoretical model is presented for calculating icing intensity, heat of anti-icing and the thickness and vertical velocity of any brine film covering the ice surface. Wind stress effects are neglected and the brine is hence moving only by the action of gravity. It is found that the transport of brine on the icing surface reduces the icing intensity significantly. The brine movement has no effect upon the heat of anti-icing, provided no icing is permitted at all in the wet icing region.

TITLE: Influence of Ice Accretion on Activity in the Northern Part of the Norwegian Continental Shelf

AUTHOR: T.S. Jorgensen

SOURCE: Offshore Technology Testing & Research Group, Trondheim
Report N° 5TF88 F82016 1982

ABSTRACT:

The report is an approach to the problems of icing on offshore activity based on a literature survey on icing at sea. The various meteorological and vessel- and structure-dependent factors of significance to the phenomenon of icing, and the hazards of icing on vessels, platforms and helicopters are discussed.

The work carried out to improve the safety by introducing minimum ice loads, and the probabilities of icing dependent on meteorological conditions and various waters are described.

Actions against icing as icing warnings, design and handling of vessels and platforms are discussed, and various mechanical, thermal and chemical de-icing and anti-icing methods are described.

TITLE: Some Aspects of Ice Formation with Special Reference to the Marine Environment

AUTHOR: Lock, G.S.H.

SOURCE: Transactions of the North East Coast Institution of Engineers & Shipbuilders 1972

ABSTRACT:

The study attempts to give an understanding of the thermal and dynamic characteristics of atmospheric ice in general and accretion on ships in particular. A detailed description of wind tunnel experiments is reported and comments are made on various techniques for controlling shipboard ice.

TITLE: Investigation & Research on Anti-icing & De-icing Devices for Marine Application

AUTHOR: S. Loset

SOURCE: International Workshop on Offshore Winds and Icing 1985

ABSTRACT:

Drilling rigs and ships, supply vessels and standby boats for all year operation in the hostile waters offshore Northern Norway need to be winterized in order to obtain high regularity and safety. The Norwegian Marine Technology Research Institute A/S (MARINTEK) has therefore tested cost-effective anti-icing and de-icing devices for use on these offshore units in order to prevent or reduce ice accretion which might occur offshore Northern Norway.

This paper describes some laboratory experiments performed in MARINTEK's climate chamber where offshore arctic climate is reconstructed, and reveal some results from the field experiments carried out offshore Northern Norway.

TITLE: Atmospheric Icing on Sea Structures

AUTHOR: L. Mankkonen

SOURCE: U.S. Army Cold Regions Research & Engineering Laboratory 1984

ABSTRACT:

The problems atmospheric icing causes for ships and offshore structures are revised. Estimation of the probability and severity of atmospheric icing based on climatological factors is discussed and theoretical methods for calculating the intensity of atmospheric icing at sea are suggested. Methods of measuring icing rate and icing prevention are also presented.

TITLE: Assessment of Ice Accretion on Offshore Structures

AUTHOR: L. David Minsk

SOURCE: CRREL 1984

ABSTRACT:

The conditions of ice accretion on vertical and horizontal surfaces are given all of which will be present in Alaskan offshore sites, data from ships cannot be applied to offshore structures and can only indicate probability but not severity conditions conductive to ship icing are given. A scarcity of appropriate meteorological data is noted, and data requirements are presented together with a method of measuring spray icing. Tests of icephobic coatings are discussed and recommendations are put forward on icing data collection and means of measuring ice accretion. Recommendations are also made on future work which should be undertaken.

TITLE: Marine Climatological Atlas - Canadian East Coast

AUTHOR: L.D. Mortsch: T. Agnew: A. Saulesleja & V.R. Swail

SOURCE: Atmospheric Environmental Service (1985) (Unpublished Manuscript)

ABSTRACT:

The Canadian east coast offshore is a frontier area where severe and often limiting environmental conditions occur. It is necessary to incorporate an understanding of meteorological and oceanographic phenomea when designing hydrocarbon exploration and production facilities and support systems, designing aircraft, and planning search and rescue operations and contingencies for the marine environment.

This marine climatological atlas was compiled as an aid for structural designers, operational planners, marine scientists, and regulatory agencies. Wind, waves, air and sea surface temperature, precipitation, humidity, windchill, ice accretion sea level pressure, flying weather, and visibility (shipping weather) are summarized. Some statistical analyses are directly applicable to design. For example, extreme value analysis of wind speed and wave height are necessary to define design loading criteria. Statistics such as percent frequency of VFR flying weather or wind roses are important for defining operating windows and contingencies.

This atlas represents a synthesis of information from ships-of-opportunity, land station, and ocean weather station Bravo data sets, the hindcast geostrophic winds (GWC), and the spectral ocean wave model (SOWM) waves. These data sets have been selected as the most appropriate for the statistical representations for design. The uses and limitations of, and the quality control checks performed on the data sets are described in Sections 2 and 3, respectively.

TITLE: Studies of Ice Accumulation on Ships Part II

AUTHOR: N. Ono

SOURCE: National Research Council (Translation)

ABSTRACT:

Ships sailing the northern seas in winter encounter the phenomenon of icing: sea water in the form of spray (or otherwise) freezes onto the ship's structures. The accretion of ice raises the vessels' center of gravity and causes a marked loss of stability, which may finally lead to capsizing. The accumulation of ice on ships is therefore to be classed as one cause of marine disasters. On a small fishing vessel, operations may be suspended when icing begins and the whole crew may be employed in removing the ice. But when the rate of icing goes up into the tons per hour and ice removal does not keep pace with ice accretion, or when the crew has no knowledge of icing, then finally the disaster of capsizing occurs. If steps are to be taken in good time to prevent such disaster, it is essential to have information on the ice accretion process. We need to observe the conditions for icing to occur, and the weights of ice accreted; we need studies of how icing affects stability, so that the safety characteristics of the ships may be improved; we need to examine methods for the prevention of icing and we need to enhance the efficiency of ice removal.

The Maritime Safety Agency undertook to carry out, each winter from 1960 on, a series of tests with ships at sea, using the Agency's patrol ships and others. The results for each year have been reported pari passu [1-4], and the findings of the tests up to and including 1962 have been recapitulated in a previous paper [5].

MELVILLE SHIPPING LTD

TITLE: Icing of Ships

AUTHOR: V.V. Panov (1976)

SOURCE: Translation - Polar Geography II (3) P166-86 July-Sept. 1978

ABSTRACT:

The increasing use of Arctic shipping lanes by the Soviet Union has focused attention on the problem of icing of ships, mainly from sea spray formed during strong wave motion or as a combination of precipitation and spray. Icing poses a threat in ice-free seas rather than in drift ice, and the highest frequency has been observed in the Barents Sea, at the western end of the Arctic shipping route, and in the Bering Sea and Sea of Okhotsk, at the eastern end, the most common period being December through March. In the central portion of the Arctic (Kara, Laptev, East Siberian and Chukchi seas), icing poses a problem during the summer shipping season (June through November). Icing conditions are analyzed on the basis of Soviet and non-Soviet observations.

TITLE: The Probability & Intensity of the Icing Up of Ocean Going Vessels

AUTHOR: A.N. Shekhtman

SOURCE: Ministry of Defence 1968 (Translation 1971)

ABSTRACT:

This paper reviews the conditions which lead to ice accretion on ships statistics are presented for the winter of 1965-66 in the Barents Sea, Norwegian, Greenland and Berring Seas and Seas of Japan and Okhotok which show that fast, slow and constant icing occurs over a wide range of temperatures of $+6^{o}$ to -1.7^{o}C. Although sea spray is the primary cause of ice accretion, atmospheric icing can also lead to dangerous conditions on board ship.

TITLE: Hydrometeorolcgical Conditions in the Icing of Vessels at Sea

AUTHOR: A.N. Shekntman

SOURCE: Naval Research & Development and Administration, Ministry of Defence 1971

ABSTRACT:

A survey is given of literature about the icing-up of vessels and the results of a summary of several hundred factors concerning this dangerous occurrence and the accompanying hydrometeorological conditions. The circumstances of icing-up are defined more accurately, and recommendations for the further study of hydrometeorological factors which influence the icing-up of vessels are given.

TITLE: Icing of Fishing Vessels in Canadian Waters

AUTHOR: J.R. Stallabrass

SOURCE: National Research Council 1975

ABSTRACT:

The icing-up of their vessels is a perennial hazard faced by crews fishing in cold northern waters. This is particularly true for the Canadian east coast fisherman each winter, since conditions conductive to icing may exist from the moment he leaves port and at any time while steaming to or from the fishing grounds and while actually fishing; in fact his whole trip lies within a zone of potential icing.

The conditions necessary for ship icing are generally accepted (but with some disagreement as to precise limits) to be the simultaneous occurrence of air temperature of $-2^{o}C$ or lower, water temperature of $+6^{o}C$ to $-2^{o}C$, and wind speed greater than 20 knots. In addition the vessel's speed and heading relative to the wind and sea must be such as to produce significant amounts of spray over the vessel. If atmospheric precipitation, fog or sea smoke prevails in addition to sea spray, the combined effect is to produce more severe icing than would result from one source alone.

To effectively combat the icing problem it is first necessary to have a thorough understanding of its causes and the physical processes involved as well as an awareness of the true extent of the hazard. This paper presents a review of the present knowledge of these processes as well as offering a tentative assessment of the extent of the problem as related to the Canadian fishing fleets.

TITLE: Trawler Icing - A Compilation of Work Done at N.R.C.

AUTHOR: J.R. Stallabrass

SOURCE: National Research Council 1980

ABSTRACT:

This report collates and reviews the results of an eleven-year project on the icing of fishing trawlers.

Initially the factors causing the icing of ships at sea are presented and some aspects of the physics of the icing process are discussed.

Some simple icing tests on cylinders of various diameters are described. These were made in an icing wind tunnel and demonstrated the effects of air temperature and cylinder size on the resulting ice formations. Later, a number of possible methods for reducing the icing hazard were tested in the wind tunnel and at an outdoor test rig. Of the methods tested the most effective was an inflatable rubber de-icing blanket.

Throughout the project, icing report forms were distributed to vessels operating out of Canadian east coast ports. The data obtained by this means has helped to establish the types of weather systems responsible for icing conditions, the geographical extent of the occurrence of icing, and statistics on the severity of icing encounters in the study area.

Appendices present simplified formulae for the droplet collection efficiency of cylinders and rectangular bodies, the derivation of an analytical expression for the rate of ice build-up on fishing trawlers, and a bibliography of ship icing.

TITLE: Research on Prevention of Ship Icing

AUTHOR: T. Tabata

SOURCE: Hokkaido University Institute of Low Temperature Science (1964)

ABSTRACT:

It is well known that on ships sailing the northern seas in winter, the phenomenon of icing may occur: sea spray or sea-surface fog ("Arctic smoke") freezes onto the ship's structure. During the first world war icing proved very troublesome for naval vessels on the North Atlantic; during the second world war icing was responsible, it is said, for the sinking of a British battleship. In 1955 it was reported in the news that two 1200-ton trawlers were sunk off Greenland as a result of icing. In the Soviet Union too the number of ships lost by icing has risen to a quite considerable total, and in USSR shipbuilding practice the loss of stability due to icing is now being taken into account, on the basis of predicting probable amounts of ice accretion.

As for Japan, with the area of fishing operations extended as in recent years, there is no way of recording how many fishing vessels may have been lost by ice accretion in the regions off the Soviet Far Eastern Maritime Province, the Kamchatkan Peninsula, and the Kurile Islands.

In Great Britain, the United States and elsewhere, research on the facts of ice accretion has been in progress. In Japan too icing research was carried out by the Maritime Safety Agency in the period 1960-1964, and we have obtained a clear picture of the influence of icing on ship stability. We are, furthermore, working out ice norms for patrol vessels: That is, criteria for the amounts of ice accretion that should be allowed for in ship design.

In spite of these research efforts, however, the relationships of ice growth to atmospheric and sea conditions are still inadequately resolved. Moreover, no successful methods for preventing ice accretion or getting rid of accreted ice have as yet been established.

MELVILLE SHIPPING LTD

TITLE: Hydrometeorolcgical Conditions Causing Ice Accretion on Ships

AUTHOR: G.V. Vasil'yeva

SOURCE: Rybnoye Khoxiaistva (Fisheries) 1966

ABSTRACT:

The article presents information on the hydrometeorological conditions which favour ships and ice accretion and briefly discuss the weather conditions which promote icing.

TITLE: Icing & De-icing of Marine Radar Aerials

AUTHOR: H.L.H. Ward

SOURCE: Ministry of Defence Navy Department U.K. 1970

ABSTRACT:

This report describes tests which were carried out in a climate test chamber to assess the effects of ice accretion on continuously rotating commercial radar aerials the results indicated a very high loss in radar performance caused by only 1/4" to 1/2" of ice, and it is considered important that some means be devised for removing ice or preventing its formation. Tests are currently being conducted on the effectiveness of a pnumatic system using an inflatable rubber "overshoe" fitted over the front of the aerial.